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# THERMAL DESIGN AND OPTIMIZATION OF THE SELF-HEATING GROUP RATION

By

**Keith Nelson**

August 1996

Final Report

October 1992 - September 1993



**UNITED STATES ARMY SOLDIER SYSTEMS COMMAND**
**NATICK RESEARCH, DEVELOPMENT AND ENGINEERING CENTER**
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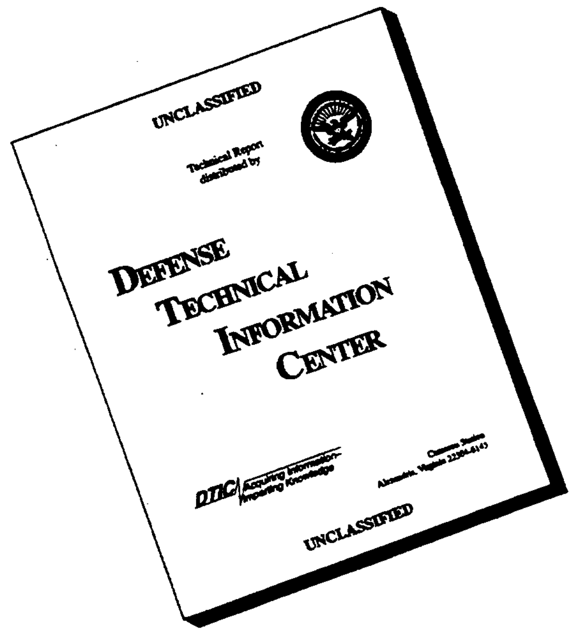


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Two mathematical heat transfer models were developed using a Finite Difference Method (FDM) and ANSYS (a commercial Finite Element Analysis (FEA) program) to improve the thermal performance of the Self-Heating Group Ration (SHGR). The FDM model was primarily used to estimate food temperatures for various foods in the SHGR. The ANSYS model was used primarily to optimize the design of the container. The analysis showed the current design of the SHGR was adequate in preventing heat loss and in heating various foods.

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| | | |
|---|---|---|
| | TRANSFER MODELS | HEAT LOSS |
| THERMAL ANALYSIS | FINITE DIFFERENCE METHOD | CHEMICAL HEATERS |
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## SYMBOLS, ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| FDM | Finite Difference Method |
| FEM | Finite Element Method |
| FRH | Flameless Ration Heater |
| | |
| SHGR | Self-Heating Group Ration |
| SHIMM | Self-Heating Individual Meal Module |
| | |
| A | Area |
| °F | degrees Fahrenheit |
| in | inches |
| $h_c$ | Convective heat transfer coefficient |
| h | hours |
| i.e. | that is |
| k | Thermal conductivity |
| lb | pounds |
| min | minutes |
| p | density |
| vs | versus |
| q | heat flow in Btu/hr*linear ft |
| q" | heat flux in Btu/area*hr*linear ft |
| TEMP | Temperature in degrees Fahrenheit |
| t | Time |
| dt | Time step |
| $T_1$ | Temperature of Node 1 |
| $T_f$ | Temperature of fluid |
| x | distance between nodes |
| ^x | volume of node element |
| $U_o$ | Internal energy of node 0 |

## PREFACE

This work was conducted by the Advanced Technology Branch in the Sustainability Directorate (SusD). The purpose of the study was to evaluate the thermal performance of the SHGR using both the FDM and FEM analysis. The work unit title of the project was "Thermal Analysis & Design Optimization" and was in essence the second part of the project "Thermal Design Optimization of Self-Heating Food Packages" project. The project began in October 1992 and ended in September 1994.

The author gratefully acknowledges the contributions of Mr. Donald Pickard and Mr. Peter Lavigne of the SusD for their guidance and assistance in data collection. The author also extends appreciation to Mr. Il Young Kim of the Science and Technology Directorate (ST&D) for his technical support in the use of ANSYS. Finally, the author would like to thank Joanne Bellantoni of SusD for helping type the report and prepare the detailed figures.

THERMAL ANALYSIS AND OPTIMIZATION
OF
THE SELF HEATING GROUP RATION


SUMMARY

In this study the Finite Difference Method (FDM) and Finite Element Method (FEM) were used to simulate the heat transfer within the Self-Heating Group Ration (SHGR). The FDM model primarily generated temperature versus time plots for different types of foods. The FEM model primarily predicted the heat losses from the SHGR container, and optimized the design of the container.

Three experimental results using corn, beef stew, and water in the SHGR verified the FDM and FEM models. The FDM model then generated temperature versus time plots for potatoes and peas. The FEM model determined the heat losses for the current form of the SHGR container. The analysis revealed that 90% of the heat loss from the container went through the bottom side. Another ANSYS's model using 1 inch styrofoam on the bottom of the SHGR, reduced the total heat loss from the container by 35.5%. Yet, the total heat lost from the standard configuration was only 0.6% of the total heat input.

A final analysis performed on the standard configuration of the SHGR determined the heat loss from the container in a cold environment (40$^{o}$F). The heat loss from the SHGR container in the cold environment was still only 1.14% of the total heat input. The analyses indicated the current design of the SHGR container is adequate to contain the heat produced by the chemical heaters when heating the food pouches.

## OBJECTIVE

The objective of this study was to:

1. Develop models to simulate the heat transfer inside the Self-Heating Group Ration (SHGR) using the Finite Difference Method (FDM) and a commercial Finite Element Method (FEM).
2. Predict temperature versus time profiles for different food items using the FDM model.
3. Optimize the thermal design of the container for the SHGR with the FEM model.

## BACKGROUND

### The Self-Heating Group Ration

The SHGR is a new design using chemical heaters similar to the Flameless Ration Heater (FRH). The chemical heaters fit into trays with thermostabilized food pouches placed on top of the heaters. The SHGR is a complete, self-contained heating system for small groups (i.e., 12 or 18 persons). It has four pouches and trays stacked together resulting in good thermal heating for the interior pouches that receive heat on both sides. Tubes connect the trays and channel the activating solution to each tray in equal amounts from a collapsible bottle. The collapsible bottle has a hole in its cap to fit over the top tube. A fiberboard box with a half-inch of styrofoam on the top and bottom contains the pouches of food and trays. Figure 1 is an illustration of the cross-section of the SHGR and shows the location of the thermocouples (for testing) and nodes (for the FDM). The SHGR fits into another carton containing accessories, utensils, beverage powders, etc. necessary for a complete self contained group meal.

The chemical heaters used for the SHGR generate an exothermic chemical reaction by using metallic compounds that react with an activating solution. During the reaction the temperature quickly increases to 200°F. The FRH pads begin to cool after approximately 10 minutes. The reaction generates most of its heat in the first 15 minutes.

The SHGR is proposed as a possible substitute for Tray Rations (T Rations) since it requires only 1600 mL of water to heat rations for 12 or 18 people, and requires no equipment for ration preparation. This is the first modeling attempt at optimizing the SHGR performance. The primary objective is reducing the heat loss from the container.

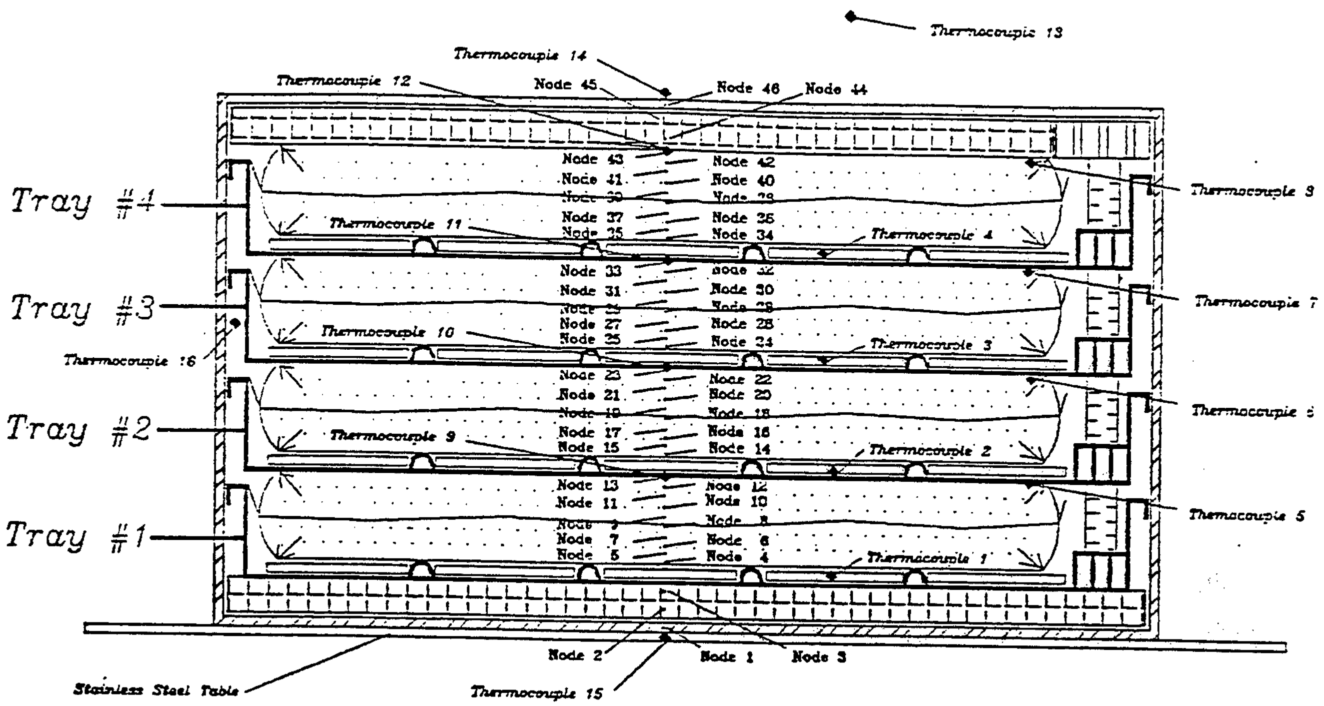



Figure 1: Self-Heating Group Ration (SHGR) with node and thermocouple locations.

## Other Models

Several people have modeled other FRH's containers to find better designs. Both the Meal, Ready-to-Eat (MRE) packages and the Self-Heating Individual Meal Module (SHIMM) were modeled using the FDM and FEM. The first model developed was a one-dimensional model using the FDM.

1. FDM.

Professor Satish Kandlikar from Rochester Institute of Technology in New York developed this first FDM model. The model simulated the heat transfer inside the MRE packages that use a single FRH.[1] Professor Kandlikar based the FDM on the Crank-Nicholson formulation. Kandlikar used a constant temperature loading condition for the FRH, the temperatures used were 95 and 100°C (203 and 212°F). When Kandlikar added an additional 15% area to the FRH model, the numerical and experimental results showed good agreement. The additional FRH area accounted for the diffusion of heat along the wetted fiberboard sides of the heater. The heater area is 20 $in^2$, but the fiberboard enclosing the heater is 24.8 $in^2$, an additional 24% contact area. The heater becomes hot quickly, heating the wetted fiberboard near the heater, which provides an added heat surface.

A sensitivity analysis performed by Professor Kandlikar revealed that the FRH cover was not a significant resistance in the transfer of heat to the MRE. Further analysis revealed the only way to reduce the size of the FRH was to add an insulative box. Still, a reduction in FRH size had to be evaluated against the cost, added mass and volume of additional insulation. The project officer, Don Pickard determined the additional insulation was too costly and bulky to include with the MRE. During Professor Kandlikar's experimentation an additional heat transfer mechanism was discovered. The additional heat transfer occurred from the FRH producing steam that was condensed onto the MRE for an added convective heat gain.

2. FEM.

W.R. Robertson and V. Sundarraj conducted the second modeling effort under the direction of Professor Satish Kandlikar.[2] They modeled both the MRE packages and the SHIMM using the FEM. The FEM they used was a commercial package developed by the Swanson Company called ANSYS.

Because of Kandlikar's[1] previous work, Robertson and Sundarraj included steam generated by the FRH in modeling the MRE packages with the FEM. The FEM analysis indicated that distributing the steam uniformly over the entire top surface of the package caused the latent heat of vaporization from the steam to be transferred to the food rapidly. Their calculations showed that by this use of the steam, the mass of the FRH pad could be decreased by up to 50%.

Robertson and Sundarraj also found that using a diffuser to direct the steam over the MRE package resulted in a 12.2$^{o}$F temperature rise over the standard MRE package. They modeled a diffuser in the MRE package in ANSYS by adding a constant temperature boundary condition of 120, 140, 160, 180, and 190°F. The constant temperature formed a convective boundary condition that simulated the condensing steam. The 120°F constant temperature boundary condition matched the experimental results. They also modeled an adiabatic boundary condition for the current or standard MRE configuration. The results of the experiments with the standard MRE package were also in close agreement with the ANSYS model.

Full size, half size and full sized grooved FRHs were simulated in the FEM model of the SHIMM. The experimental and numerical results were in agreement for most cases of the SHIMM. Robertson and Sundarraj's study found the SHIMM's two full size FRHs adequate for achieving the desired heating characteristics, a half-size FRH was not.

3. ANSYS.

Mr. Il Young Kim of U.S. Army Soldier System Command, Natick Research, Development and Engineering Center (NRDEC)[3] engineered the third modeling effort. Mr. Kim also modeled the SHIMM using ANSYS. The SHIMM was modeled using three different heater sizes,including full, half and two-thirds size. Kim used varying temperature loads for the heaters in the ANSYS model based on the experimental results of the one, one-half, and two-thirds sized FRHs. The analysis revealed that two one-third sized FRHs evenly spaced beneath the food could completely heat the food in the SHIMM.

Mr. Kim also performed a material analysis of the material between the FRH and the food. The materials considered were polypropylene, polyethylene, tin (Sn 100), and aluminum foil. Tin was the superior material to transfer the heat of the FRH to the food in the SHIMM. Mr. Kim proposed heat sealing the tin into the tub of the SHIMM. He also proposed a new design concept for the SHIMM. In the new design the SHIMM would be made in a tin container like the Tray ration (T-ration) and snap-fit into a polymeric container containing two one-third size FRHs.

## INTRODUCTION

The SHGR has four trilaminate pouches of food. Each pouch of food weighs approximately 6.6 pounds and contains enough food for approximately 12 or 18 people depending on the entree. The food pouches for this study lay on top of four FRHs that fit into a polypropylene tray. The SHGR consisted of four trays (holding the pouches and heaters) stacked on top of each other with a half-inch of styrofoam on the top, and bottom. A fiberboard box contains the trays, pouches of food and Styrofoam™ (Figure 1).

During experimental testing the FRH pads substituted for the larger, unavailable chemical heating pads. These larger chemical heating pads completely fill the bottom of the polypropylene trays, but the four FRH pads covered approximately 60% of the bottom. The total heat input to each pouch of food was 520 Btus (four FRHs).

The modeling of the SHGR consisted of both a FDM and FEM analysis. The FDM model utilized the backward difference method and the code was written in FORTRAN. The FEM model was developed in ANSYS (a commercial code developed by the Swanson Company). The FDM model was a one-dimensional model and the FEM model was a two-dimensional model. The FDM and FEM models' accuracy was verified by three experiments. Upon completion of the verification of the models, the FDM and FEM models were used for analysis of the SHGR. With the FDM model the type of food was changed to determine the significance the food would have in the design of the SHGR. In the FEM model two parameters were tested. Styrofoam thickness was the first parameter (half-inch versus one-inch) adjusted to minimize heat loss. (The second parameter varied was the ambient temperature to determine the effect it would have on the design of the SHGR.)

## APPROACH

A one-dimensional FDM model was developed using the implicit or backward-difference technique. Equations for the SHGR were developed and written in FORTRAN. The physical properties gathered were plugged into the FORTRAN code for simulating the heat transfer within the SHGR.

Three experiments were conducted after completing the FDM code. The same experimental results were later used to verify the two-dimensional FEM model in ANSYS. In the experiments the SHGR had water, corn or beef stew for foods. After the FDM model had been verified against the experimental results, it predicted temperature versus time for different food items (i.e., potatoes, and peas).

After the completion of the FDM model the two dimensional FEM model in ANSYS was developed. After the ANSYS model was completed and verified against the experimental results, a heat loss analysis was completed on the container of the SHGR. The SHGR was then modeled with an additional one-half inch of insulation on the bottom of the container and again a heat loss analysis performed. The last model tested in ANSYS was the standard or current SHGR model placed in cold climatic conditions (40°F). A final heat loss analysis was done to determine the effectiveness of the SHGR in cold environmental conditions.

## FINITE DIFFERENCE METHOD

The implicit finite difference technique was used to model the SHGR because it has the advantage of having a time derivative that is stable for all node spacing and time intervals. However, smaller time intervals and node spacing will lead to more accurate solutions. The disadvantage as compared to the explicit method or forward-difference technique is that all the algebraic equations must be solved simultaneously, requiring more computer memory. However, for modeling the SHGR, computer memory was not a problem. The equations used for the implicit method were as follows,

$$kA\,\frac{T_1^{t+dt} - T_0^{t+dt}}{x} + kA\,\frac{T_2^{t+dt} - T_0^{t+dt}}{x} = pA\hat{x}c\,\frac{T_0^{t+dt} - T_0^{t}}{dt} \qquad (1)$$

where k is the thermal conductivity, A is the contact area, $T_0$, $T_1$, and $T_2$ are the temperature of nodes 0, 1, and 2 respectively, x is the distance between the nodes, t is the time, dt is the time step, p is the density and ˆx is the length of the node. Note that ˆx is the same as x, if the node spacing is the same. If the distance between nodes is not the same, x on the left side of equations (1) and (3) below is the distance between the nodes and ˆx for the right side of equation (1) and (3) below is the width of node 0.

Equation (1) (for the interior nodes) is derived from the arrangement of nodes shown in Figure 2, where:

$$q_{1-0} + q_{2-0} = dU_o/dt \tag{2}$$

```
         Solid
     Properties: k,p,c
     |           |           |
     |-----x-----|----x------|        Note: x equals ^x
     |           |           |              for equal node
     1           0           2              spacing.
     o===========o===========o
|           |          |          |
|----^x-----|---^x-----|---^x-----|
|           |          |          |
```

Figure 2: Node arrangement for equation (1) and (2).

On the right side of equation (2), $U_o$ is the internal energy of node 0 as it varies with respect to time. The heat flow terms in equation (2) are approximated by the finite-difference form of Fourier's law in the first two terms in equation (1).

For a one-dimensional solid in contact with a fluid (i.e., air and SHGR container) the following equation was used:

$$kA\,\frac{T_1^{t+dt} - T_0^{t+dt}}{x} + h_c A(T_f - T_0) = \frac{pA\,\hat{}x c}{2}\;\frac{T_0^{t+dt} - T_0^{t}}{dt} \tag{3}$$

Equation 3 was derived from the following arrangement of nodes shown in Figure 3, where:

$$q_{1-0} + q_{f-0} = dU_0/dt \tag{4}$$

```
|            |       |
|      1     |      0|     Fluid
|      o=============o     h_c, T_f
|            |       |
|---^x-------|-^x/2- |
|            |       |
```

Figure 3: Node arrangement for equations (3) and (4).

For equations (3 & 4) $h_c$ is the convective heat transfer coefficient and $T_f$ is the temperature of the fluid.

## COMPUTER PROGRAM FOR FDM MODEL

The name of the first program is GRP3.FOR. A copy of GRP3.FOR can be found in Appendix A. GRP3.FOR contains the equations written for the distances between the forty-six nodes. The GRP3.FOR program calculated the matrix coefficients based on equations (1) and (3) for the SHGR, and then wrote the result in file 'GC'. The input file for GRP3.FOR was 'PV'. The 'PV' file contains primarily the material properties for the SHGR. Appendix B contains a sample of the 'PV' file.

The 'GC' file then became the input file for the second program GROUP3.FOR. A copy of the GROUP3.FOR program can be found in Appendix A titled, Part II of the Finite Difference Program. The other input files for GROUP3.FOR were the temperatures from the FRH pads for each minute. The temperatures used were from the experimental results. The temperatures from the experiments for the FRH pads in the bottom three trays were averaged because they were similar and there weren't enough thermocouples for each heater in the trays. For the top tray the FRH pad temperatures were quite different so a separate file was made for the model. 'TC' was the first of the two input files for the FRHs temperatures in the bottom three trays. 'TCTOP' was the second input file and it contained the temperatures for the FRHs in the top tray of the FDM model. Samples of both TC and TCTOP can be found in Appendix B.

The MATINV SUBROUTINE in GROUP3.FOR solved the coefficient matrix by matrix inversion, and then GROUP3.FOR calculated new temperatures for each time iteration. The 'OUT.WQ1' file contained the solution in two formats. The first format in the file listed the node temperatures at each time iteration. The second output listed all the temperatures for each node for the complete time span, one node at a time. In the second format the nodes were aligned in columns that made the data easy for parsing in Quattro Pro TM. Quattro Pro TM (a computer spreadsheet) was used to graph and compare the experimental results with the FDM results. The output also contained the average food temperature for each tray at each time interval. The average food temperature was calculated by summing the temperatures within the food at each node and dividing by the number of nodes. A sample of one output file can be found in Appendix B.

## EXPERIMENTAL PROCEDURE

The three experiments performed with the SHGR were in the configuration shown in Figure 4. Ninety-eight cubic inches (160 ML) 3.6 water activated the 16 FRHs in the SHGR. Each pouch contained 6.6 lb. of water, corn or beef stew.

Sixteen thermocouples, connected to the digi-strip and SHGR recorded the temperatures. The first four thermocouples recorded the temperature of one FRH in each tray. The second set of four thermocouples recorded the temperature of the food near the edge and on the top side of each pouch. The third set of four thermocouples recorded the temperature at the top center of each pouch of food. Both the second and third sets of (four) thermocouples were placed on the outside of the food pouches. These thermocouples had a small fiberboard square on top and tape over the fiberboard to shield the thermocouples from direct heat from the FRHs. The thermocouple positions were not in the most desired positions, but previous experiments conducted by Mr. Peter Lavigne had shown the final temperature of the food to coincide with the final thermocouple readings. The final set of four thermocouples recorded the ambient temperature and the temperature on the top, bottom, and inside air space (along the side) of the SHGR.

The digi-strip recorder was connected to a Memtec TM tape recorder to record the 16 temperatures every minute. The Memtec TM tape recorder was connected to a serial port of a 286 computer at the conclusion of each test. The data were downloaded to Lotus Measure TM in a Lotus 123 TM format. The Lotus files were then imported into Quattro Pro TM and graphed against the FDM model results.

## EXPERIMENTAL RESULTS

In the first experiment water was used in the food pouches. The resulting temperatures of the water from experiment 1 are graphed in Figure 5 (note: test #1 is substituted for Experiment 1 in the subtitle of the graph because of the lack of space in the software subtitle blank). Table 1 gives the tabulated values from experiment 1.

In the second experiment corn was in pouches one, two, and four and beef stew was in the third food pouch. Figure 6 contains the resulting temperatures of the corn and beef stew from experiment 2. Table 2 gives the tabulated values for experiment 2.

# EXPERIMENTAL CONFIGURATION

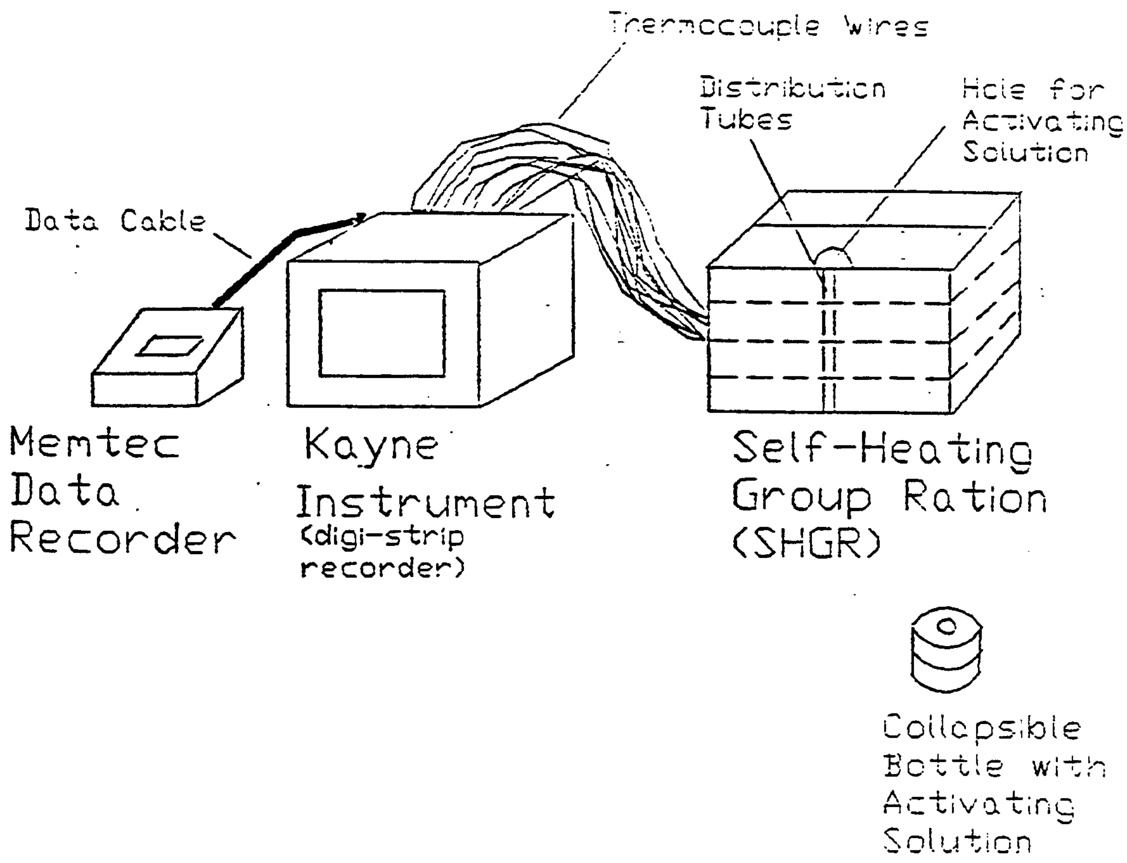



Figure 4: Self-heating group ration experimental configuration

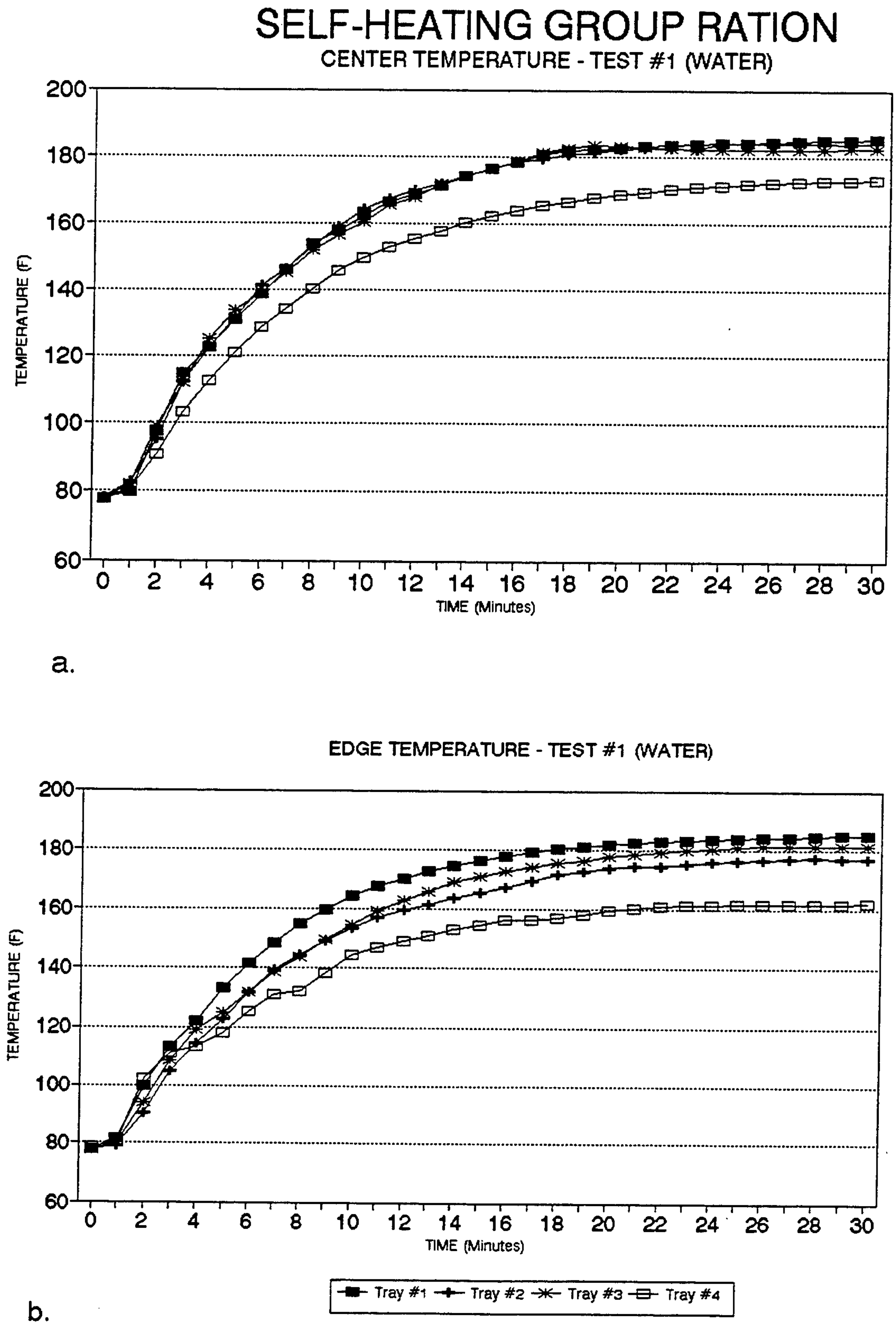



Figure 5: SHGR center and edge food temperatures for each tray in experiment 1.

# Table 1. SHGR Test Data from Experiment 1

(Water in all trays & Temperature in F)

| Time | HEATERS | | | | Avg. of | EDGE TEMPERATURES | | | | Avg. of | CENTER TEMPERATURES | | | | Top | Bottom | Side |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (min) | tray 1 | tray 2 | tray 3 | tray 4 | 1,2,3 | tray 1 | tray 2 | tray 3 | tray 4 | 1,2,3 | | tray 2 | tray 3 | tray 4 | of Box | of Box | Inside Box |
| 0 | 77.7 | 77.9 | 77.8 | 77.6 | 77.8 | 78 | 78.2 | 77.9 | 78.6 | 78.0 | 77.9 | 78.1 | 78 | 77.8 | 81.8 | 77.8 | 80.3 |
| | 197.4 | 198.7 | 197.4 | 199.9 | 197.8 | 81.8 | 79.2 | 80.4 | 80.2 | 81.6 | 79.9 | 82.9 | 82 | 81 | 82 | 77.8 | 80.4 |
| 2 | 192.5 | 201.7 | 194.8 | 198 | 196.3 | 99.8 | 90.5 | 94.1 | 102.2 | 97.4 | 97.5 | 95.4 | 99.2 | 90.9 | 81.9 | 78.2 | 81.1 |
| | 196.1 | 199.6 | 198 | 198.4 | 197.9 | 113.3 | 104.7 | 108.8 | 111 | 113.1 | 115 | 112.3 | 112 | 103.5 | 82.6 | 79.1 | 81.7 |
| 4 | 191.2 | 195.9 | 198.9 | 196.3 | 195.3 | 122.1 | 114.2 | 119 | 113.2 | 123.7 | 122.9 | 122.8 | 125.4 | 112.9 | 83.5 | 80.2 | 81.8 |
| | 194.2 | 194.5 | 197.9 | 196.8 | 195.5 | 133 | 122.6 | 124.9 | 117.9 | 132.2 | 131 | 131.6 | 134 | 121 | 84.4 | 81.2 | 81.9 |
| 6 | 197 | 196.8 | 197.8 | 197.9 | 197.2 | 141.4 | 131.6 | 131.8 | 125.2 | 139.9 | 138.8 | 141.5 | 139.3 | 128.8 | 85.3 | 82.3 | 82.2 |
| | 199.1 | 197.3 | 197.2 | 195.4 | 197.9 | 148.4 | 139.6 | 138.6 | 131.2 | 146.0 | 146.2 | 146.4 | 145.3 | 134.5 | 86.3 | 83.5 | 82.3 |
| 8 | 200.5 | 197.6 | 197.1 | 192.5 | 198.4 | 155 | 144.6 | 143.8 | 132.3 | 152.9 | 153.8 | 153.2 | 151.8 | 140.6 | 87.5 | 84.7 | 82.5 |
| | 200.9 | 198.1 | 195.9 | 188.5 | 198.3 | 159.7 | 149 | 149.6 | 138.5 | 157.7 | 157.6 | 159 | 156.4 | 145.8 | 88.6 | 85.8 | 82.8 |
| 10 | 201.5 | 197.6 | 197.3 | 186.5 | 198.8 | 164.6 | 153.6 | 154.6 | 144.2 | 162.2 | 162.3 | 164 | 160.4 | 149.6 | 89.5 | 87 | 82.9 |
| | 201.3 | 197.1 | 198.4 | 183.8 | 198.9 | 167.9 | 157.2 | 159.4 | 146.9 | 166.4 | 166.3 | 167.4 | 165.5 | 152.9 | 90.7 | 88.1 | 83.1 |
| 12 | 200.5 | 196.6 | 197.2 | 182.9 | 198.1 | 170.4 | 159.6 | 162.7 | 149.3 | 168.9 | 168.9 | 169.9 | 167.8 | 155.4 | 91.4 | 89.3 | 83.4 |
| | 199.5 | 195.7 | 197.8 | 181.8 | 197.7 | 172.8 | 161.8 | 166 | 151 | 171.7 | 171.2 | 171.8 | 172 | 157.8 | 92.1 | 90.4 | 83.5 |
| 14 | 199.2 | 195.2 | 197.1 | 181.3 | 197.2 | 174.5 | 163.6 | 168.9 | 153 | 174.1 | 174.2 | 174 | 174 | 160.2 | 92.8 | 91.4 | 83.6 |
| | 198.6 | 195.1 | 197.3 | 181.1 | 197.0 | 176.2 | 165.6 | 171.1 | 154.8 | 176.3 | 176.2 | 176.3 | 176.3 | 162.1 | 93.5 | 92.4 | 83.6 |
| 16 | 198.2 | 195.6 | 197.4 | 181.1 | 197.1 | 178 | 167.2 | 172.8 | 156.3 | 178.4 | 178.5 | 178.1 | 178.6 | 163.9 | 94.5 | 93.4 | 83.6 |
| | 197.9 | 195.4 | 197.8 | 180.9 | 197.0 | 179.3 | 169.5 | 174.3 | 156.3 | 180.5 | 180.8 | 179.3 | 181.3 | 165.4 | 94.6 | 94.3 | 83.7 |
| 18 | 197.6 | 195.9 | 198.7 | 181 | 197.4 | 180.4 | 171.8 | 175.7 | 157.2 | 181.7 | 181.8 | 180.7 | 182.7 | 166.6 | 94.7 | 95 | 83.6 |
| | 197.4 | 195.8 | 200.3 | 180.6 | 197.8 | 181 | 173 | 176.7 | 158.4 | 182.4 | 182.4 | 181.4 | 183.5 | 167.7 | 95.6 | 95.7 | 83.6 |
| 20 | 197.1 | 195.7 | 201 | 180.3 | 197.9 | 181.8 | 174.1 | 177.8 | 159.7 | 182.8 | 182.6 | 182.4 | 183.3 | 168.7 | 96.1 | 96.4 | 83.6 |
| | 196.8 | 195.7 | 200.2 | 180 | 197.6 | 182.4 | 174.5 | 178.6 | 160.2 | 183.0 | 183.1 | 182.8 | 183 | 169.4 | 96 | 97.1 | 83.5 |
| 22 | 196.5 | 196 | 199.1 | 179.6 | 197.2 | 182.9 | 174.7 | 179.5 | 161.2 | 182.9 | 183.5 | 182.6 | 182.7 | 170.3 | 96.7 | 97.7 | 83.5 |
| | 196.3 | 196.1 | 198.4 | 179.4 | 196.9 | 183.4 | 175.4 | 180.1 | 161.5 | 182.9 | 183.8 | 182.5 | 182.4 | 170.9 | 96.4 | 98.2 | 83.6 |
| 24 | 196 | 196.4 | 197.4 | 179.3 | 196.6 | 183.7 | 175.9 | 180.6 | 161.7 | 183.5 | 184.1 | 184.2 | 182.3 | 171.4 | 96.5 | 98.7 | 83.6 |
| | 195.8 | 196.5 | 196.7 | 179.1 | 196.3 | 184 | 176.4 | 181 | 161.9 | 183.6 | 184.4 | 184.2 | 182.3 | 171.9 | 96.7 | 99.1 | 83.7 |
| 26 | 195.5 | 196.6 | 196 | 178.9 | 196.0 | 184.3 | 176.9 | 181.3 | 161.9 | 183.8 | 184.7 | 184.2 | 182.4 | 172.3 | 97 | 99.6 | 83.8 |
| | 195.2 | 196.6 | 195.3 | 178.8 | 195.7 | 184.4 | 177 | 181.4 | 162 | 183.8 | 184.9 | 184 | 182.5 | 172.6 | 97.3 | 100 | 83.8 |
| 28 | 194.7 | 196.4 | 194.6 | 178.6 | 195.2 | 184.6 | 177.3 | 181.6 | 162 | 184.0 | 185.1 | 184.3 | 182.5 | 172.9 | 97.1 | 100.3 | 83.8 |
| | 194.5 | 196.4 | 194.1 | 178.5 | 195.0 | 184.9 | 177.1 | 181.7 | 162.1 | 183.9 | 185.3 | 183.8 | 182.6 | 173.1 | 97.2 | 100.7 | 83.9 |
| 30 | 194.3 | 196 | 193.6 | 178.4 | 194.6 | 185 | 177.2 | 181.6 | 162.2 | 184.2 | 185.5 | 184.6 | 182.6 | 173.3 | 97.4 | 101 | 84 |

Ambient
79.7

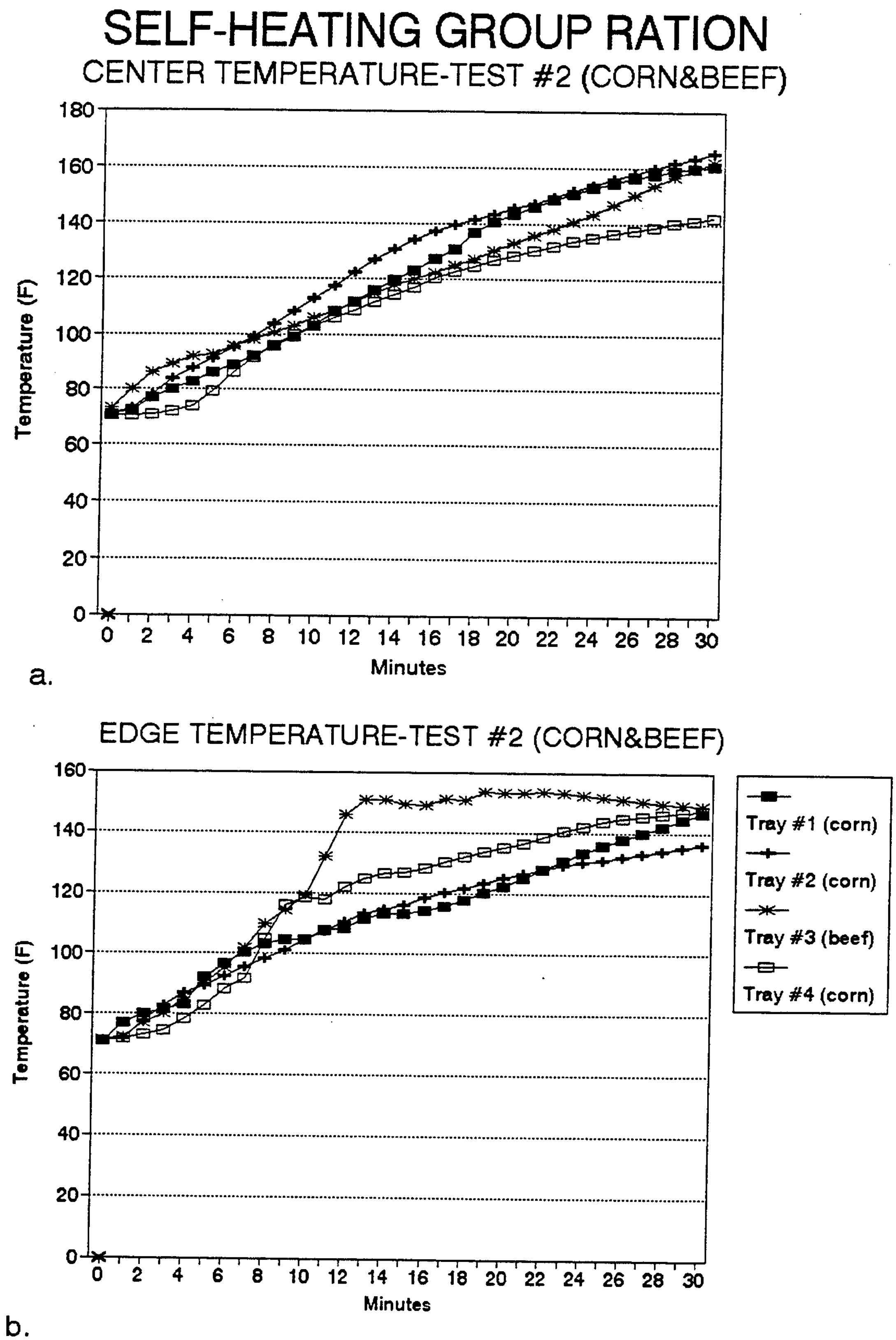



Figure 6: SHGR center and edge food temperatures for each tray in experiment 2.

# Table 2. SHGR Test Data from Experiment 2

(Beef Stew in Tray #3 & Corn in Trays #1, #2, & #3)

(Temperature in F)

| Time | Heaters | | | | Avg. of | Tray 4 | Avg. of Tray 4 | EDGE TEMPERATURES | | | | CENTER TEMPERATURES | | | | | Top | Bottom | Side |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (min) | tray 1 | tray 2 | tray 3 | tray 4 | 1,2,3 | Exp #1 | Exp.1&2 | tray 1 | tray 2 | tray 3 | tray 4 | tray 1 | tray 2 | tray 3 | tray 4 | Ambient | of Box | of Box | Inside Box |
| 0 | 71 | 70.8 | 70.6 | 70.9 | 70.7 | 77.6 | 74.3 | 71.2 | 71 | 71.6 | 71 | 71 | 70.9 | 72.9 | 70.6 | 66.7 | 72.1 | 70.6 | 73.6 |
| | 71.1 | 203.6 | 183.1 | 191.4 | 193.4 | 199.9 | 195.7 | 77 | 72 | 72.5 | 71.8 | 72.2 | 73.3 | 80.1 | 70.6 | 66.4 | 71.6 | 70.6 | 91.4 |
| 2 | 71.2 | 204.4 | 197.3 | 199.5 | 200.9 | 198 | 198.8 | 80.1 | 77.7 | 76.8 | 73.1 | 76.9 | 78.2 | 85.8 | 70.8 | 65.7 | 71.1 | 70.5 | 106.7 |
| | 71.6 | 203.6 | 199 | 198.5 | 201.3 | 198.4 | 198.5 | 81.7 | 82.7 | 80.2 | 74.8 | 80.1 | 83.8 | 89.1 | 71.9 | 65.2 | 71 | 70.5 | 117.4 |
| 4 | 71.8 | 197.3 | 199.2 | 200.7 | 198.3 | 196.3 | 198.5 | 83.4 | 86.9 | 85.3 | 78.4 | 82.6 | 87.5 | 91.8 | 74.1 | 65.9 | 70.8 | 70.5 | 126 |
| | 71.8 | 189.3 | 200.9 | 201.8 | 195.1 | 196.8 | 199.3 | 92.2 | 89.6 | 90.2 | 82.7 | 85.9 | 90.9 | 92.7 | 79 | 66 | 70.9 | 70.6 | 123.9 |
| 6 | 72 | 194.6 | 198.8 | 202.5 | 196.7 | 197.9 | 200.2 | 96.8 | 92.6 | 95.3 | 88.3 | 88.7 | 95 | 95.6 | 85.8 | 65.2 | 70.9 | 70.8 | 121.2 |
| | 72 | 201.3 | 197.4 | 202.3 | 199.4 | 195.4 | 198.9 | 100.4 | 95.5 | 101.7 | 91.8 | 91.9 | 99.1 | 97.9 | 91.5 | 64.9 | 70.9 | 71 | 123.7 |
| 8 | 72.1 | 202.7 | 198.2 | 203.5 | 200.5 | 192.5 | 198.0 | 103.4 | 98.4 | 109.8 | 105 | 95.8 | 103.5 | 100.6 | 96.3 | 64.4 | 71.1 | 71.3 | 124.3 |
| | 72.1 | 202.4 | 195.7 | 203.7 | 199.1 | 188.5 | 196.1 | 104.7 | 101.3 | 114.4 | 116 | 99.3 | 108.2 | 102.9 | 99.8 | 64.2 | 71.3 | 71.6 | 136.3 |
| 10 | 72.2 | 202.4 | 203.8 | 203.5 | 203.1 | 186.5 | 195.0 | 104.5 | 104.5 | 119.1 | 118.5 | 103.1 | 113 | 105.9 | 103 | 64.5 | 71.7 | 71.9 | 139.6 |
| | 77 | 201.9 | 204.4 | 202.7 | 203.2 | 183.8 | 193.3 | 107.9 | 107.7 | 132.3 | 117.9 | 108 | 117.4 | 108.2 | 106.1 | 64.8 | 72 | 72.3 | 140.1 |
| 12 | 81.6 | 200.8 | 204.9 | 202.6 | 202.9 | 182.9 | 192.8 | 108.4 | 110.7 | 146 | 121.9 | 111.8 | 122.4 | 112 | 108.9 | 65.4 | 72.7 | 72.8 | 144.2 |
| | 85 | 198.3 | 205 | 202.4 | 201.7 | 181.8 | 192.1 | 111.5 | 113.5 | 150.6 | 125 | 115.8 | 127 | 115.1 | 111.7 | 66.2 | 73.6 | 73.5 | 146.5 |
| 14 | 87.5 | 196.9 | 204.6 | 201.9 | 200.8 | 181.3 | 191.6 | 113.4 | 114.8 | 150.6 | 126.6 | 119.7 | 131.1 | 117.6 | 114.1 | 66.8 | 74.5 | 74.2 | 162 |
| | 89.5 | 196.4 | 204.2 | 200.4 | 200.3 | 181.1 | 190.8 | 113.5 | 116.2 | 149.3 | 127 | 123.1 | 134.4 | 120.2 | 117 | 67.3 | 75.2 | 75 | 162 |
| 16 | 90.3 | 194.9 | 204.2 | 199.1 | 199.6 | 181.1 | 190.1 | 114.3 | 118.5 | 148.9 | 128.3 | 127.3 | 137.1 | 122.6 | 120.5 | 67.6 | 75.8 | 75.6 | 153.5 |
| | 90.5 | 194.4 | 204 | 198.2 | 199.2 | 180.9 | 189.6 | 115.8 | 120.1 | 151.3 | 130.2 | 131 | 139.4 | 125.1 | 122.8 | 67.6 | 76.1 | 76.2 | 141.7 |
| 18 | 91.6 | 198.2 | 203.8 | 197.3 | 201.0 | 181 | 189.2 | 117.9 | 121.7 | 150.6 | 132.2 | 136.9 | 141.6 | 127.4 | 125 | 67.8 | 76.5 | 76.7 | 137.5 |
| | 93.1 | 201 | 203.9 | 195.8 | 202.5 | 180.6 | 188.2 | 120.2 | 123.5 | 153.5 | 133.9 | 140.9 | 143.6 | 130.2 | 127 | 68 | 77.1 | 77.3 | 139.1 |
| 20 | 94.4 | 202.7 | 203.5 | 195 | 203.1 | 180.3 | 187.7 | 122.5 | 125.2 | 153.2 | 135.1 | 143.4 | 145.6 | 133.1 | 128.6 | 67.9 | 77.6 | 77.8 | 141.1 |
| | 94.1 | 201.9 | 203.4 | 194.4 | 202.7 | 180 | 187.2 | 125.1 | 126.7 | 153.2 | 136.8 | 146.1 | 147.4 | 135.7 | 130.4 | 67.9 | 78.1 | 78.2 | 142.4 |
| 22 | 93.3 | 201.1 | 203.1 | 194.4 | 202.1 | 179.6 | 187.0 | 127.8 | 128.1 | 153.5 | 138.7 | 148.7 | 149.6 | 138.2 | 132.1 | 67.9 | 78.4 | 78.6 | 144.2 |
| | 92.7 | 199.9 | 202.8 | 193.7 | 201.4 | 179.4 | 186.6 | 130.8 | 129.3 | 153.1 | 140.5 | 150.8 | 151.9 | 140.9 | 133.7 | 68.1 | 78.9 | 79.1 | 143.4 |
| 24 | 92.5 | 198.6 | 202.5 | 193.6 | 200.6 | 179.3 | 186.5 | 133.7 | 130.3 | 152.4 | 142.1 | 152.8 | 154 | 143.6 | 135 | 68.4 | 79.4 | 79.4 | 139.9 |
| | 92.4 | 197.6 | 202.2 | 192.5 | 199.9 | 179.1 | 185.8 | 135.9 | 131.2 | 151.8 | 143.6 | 154.5 | 155.9 | 146.6 | 136.4 | 68.3 | 79.6 | 79.7 | 136.5 |
| 26 | 92.7 | 196.7 | 201.7 | 191.6 | 199.2 | 178.9 | 185.3 | 137.8 | 132.1 | 151.1 | 144.9 | 156.1 | 158 | 150.4 | 137.7 | 68.2 | 80.1 | 80 | 134.6 |
| | 93.2 | 196.1 | 201 | 190.8 | 198.6 | 178.8 | 184.8 | 140 | 133.1 | 150.4 | 145.5 | 157.6 | 159.9 | 154 | 138.8 | 68.4 | 80.6 | 80.3 | 132.9 |
| 28 | 94 | 195.6 | 200.6 | 190.2 | 198.1 | 178.6 | 184.4 | 142.3 | 134.1 | 149.8 | 146.3 | 158.9 | 161.8 | 157.1 | 140.1 | 68.4 | 80.8 | 80.6 | 131 |
| | 94.9 | 195.3 | 200.4 | 189.5 | 197.9 | 178.5 | 184.0 | 144.4 | 135 | 149.4 | 146.9 | 159.9 | 163.5 | 159.7 | 141.1 | 68.8 | 81.5 | 80.9 | 129.1 |
| 30 | 95.9 | 195.2 | 200.2 | 188.9 | 197.7 | 178.4 | 183.7 | 146.6 | 136 | 149.1 | 147.4 | 160.8 | 165.1 | 162 | 142.2 | 68.8 | 81.9 | 81.2 | 127.7 |

In the third and final experiment the third pouch contained water and the other three pouches had corn. Graphed in Figure 7 are the results of experiment 3. Table 3 gives the tabulated values for experiment 3.

In experiments 1 and 3 there wasn't any problem with the experiments. However, in experiment 2 the water distribution system did not adequately distribute the water evenly to the four trays in the SHGR. The bottom tray (tray #1) received approximately (4.9 $in^3$) 80 mL of extra water that was for the top tray (tray #4). Therefore, the FRH pads in the top tray did not fully activate. Yet the thermocouple in the top tray was in a FRH pad that fully activated, so the FRH data shown are consistent with previous experiments. The thermocouple in the bottom tray was in a FRH heater that either did not properly activate or was cooled because of the excess water. In experiment 2 the water distribution system did not affect trays #2 and #3. See Figure 8 for plots of the FRH temperatures for experiments 1, 2, and 3.

Finally in Figure 9 the plots of the top, bottom, and side temperature of the SHGR container (box) are displayed for experiments 1, 2, and 3. The side thermocouple measured the temperature of the heated air inside the SHGR container.

## FINITE DIFFERENCE MODEL VERIFICATION

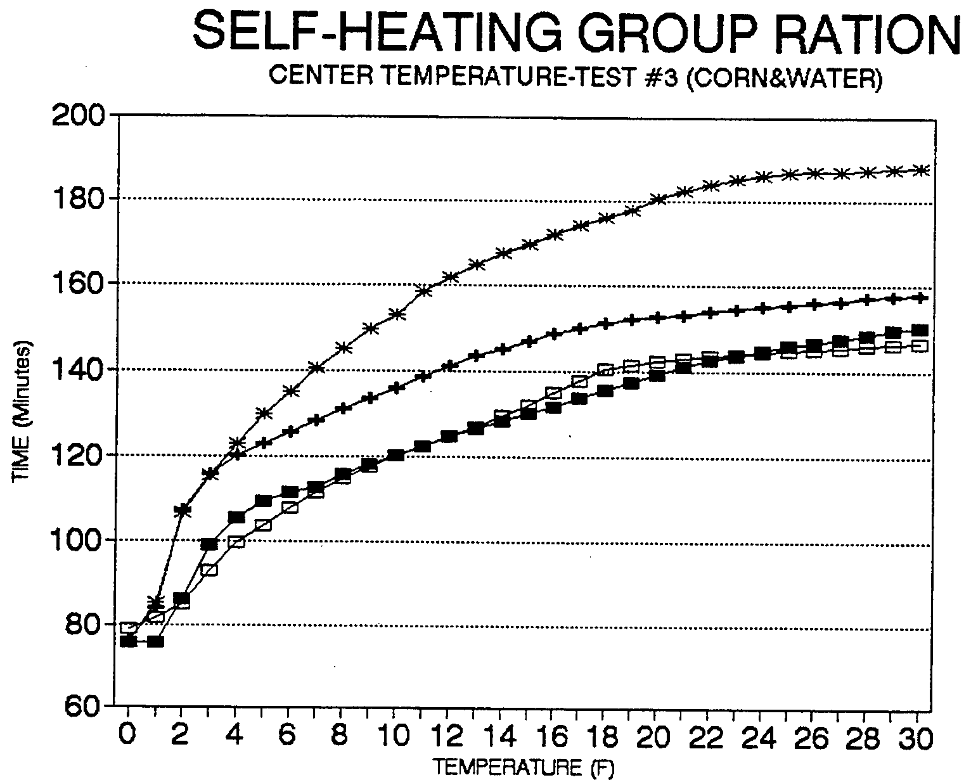
The physical properties of the materials used for the three experiments for the FDM and FEM model were as follows:

Thermal Conductivity (k) - Btu/h*ft*°F

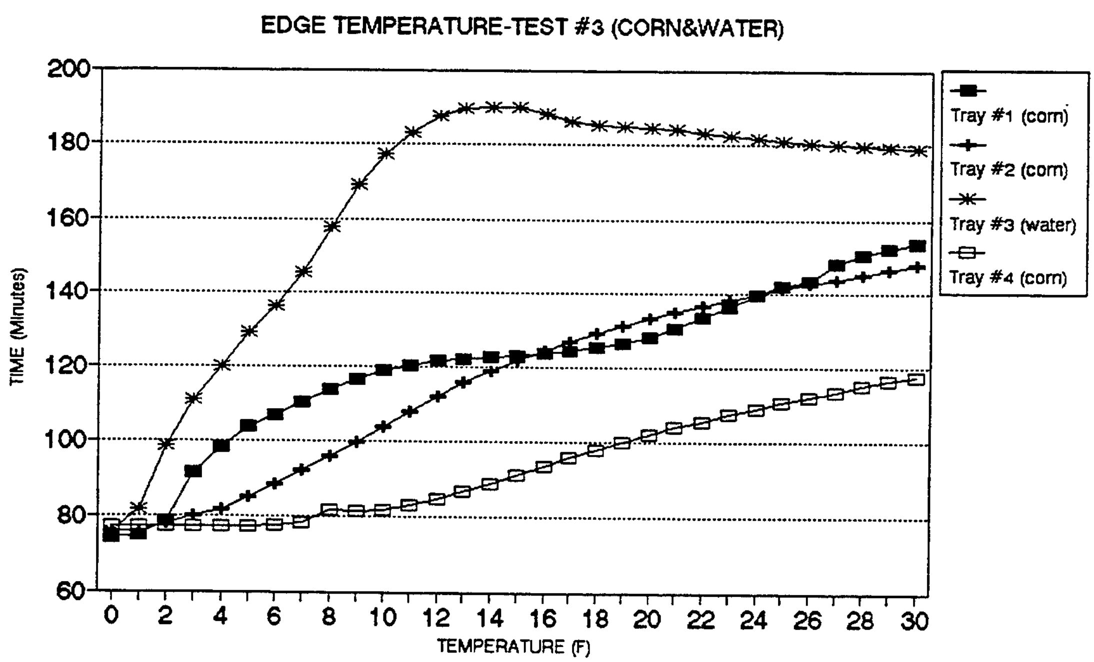
- air - 0.0177
- water - 0.375
- corn - 0.0996
- beef stew - 0.275
- polypropylene tray - 0.08
- Styrofoam™ - 0.025
- fiberboard - 0.202
- tri-laminate food pouch - 0.173
- flameless ration heater - 0.392
- stainless steel - 5.32

Specific Heat (c) - Btu/lb*°F

- air - 0.24
- water - 1.0
- corn - 0.366
- beef stew - 0.82
- polypropylene tray - 0.46
- Styrofoam - 0.48
- fiberboard - 0.58
- tri-laminate pouch - 0.51
- flameless ration heater - 0.7
- stainless steel - 0.11




a.




b.

Figure 7: SHGR center and edge food temperature for each tray in experiment 3.

# Table 3. SHGR Test Data from Experiment 3

(Water in Tray #3 & Corn in Trays #1, #2, & #3)

(Temperature in F)

| Time | HEATERS | | | | Avg. of | Tray #1 | | Tray #2 | | Tray #3 | | Tray #4 | | Top | Bottom | Side |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (min) | tray 1 | tray 2 | tray 3 | tray 4 | 1,2,3 | center | edge | center | edge | center | edge | center | edge | of Box | of Box | Inside Box |
| 0 | 74.5 | 75.1 | 75.4 | 78.1 | 75.0 | 75.5 | 74.3 | 76.5 | 75.9 | 75.8 | 75.8 | 79.1 | 77.4 | 84.4 | 78.5 | 81.2 |
| | 191 | 75.2 | 185.9 | 201.7 | 150.7 | 75.9 | 75 | 84.2 | 76.2 | 85.6 | 81.8 | 82 | 77.4 | 83.9 | 78.6 | 82.3 |
| 2 | 181.8 | 201.9 | 192.5 | 204.9 | 192.1 | 86.5 | 78.8 | 107.3 | 78.2 | 106.5 | 98.7 | 85.1 | 77.5 | 83.6 | 78.8 | 85.4 |
| | 195.9 | 203.5 | 191.7 | 203.8 | 197.0 | 99 | 91.7 | 115.7 | 79.9 | 115.4 | 111.2 | 92.9 | 77.6 | 83.7 | 79.1 | 88.6 |
| 4 | 198.8 | 204 | 196 | 203.6 | 199.6 | 105.3 | 98.6 | 120.2 | 81.9 | 123 | 119.9 | 99.7 | 77.6 | 83.9 | 79.4 | 93.3 |
| | 197 | 192.3 | 199.9 | 203.4 | 196.4 | 109.2 | 104 | 123.1 | 85.1 | 129.9 | 129.1 | 103.9 | 77.6 | 84.1 | 79.8 | 99.2 |
| 6 | 195.9 | 199.6 | 200.2 | 203.1 | 198.6 | 111.4 | 107.1 | 125.9 | 88.8 | 135.3 | 136.5 | 107.9 | 77.8 | 84.2 | 80.3 | 102.89 |
| | 193.2 | 202 | 201.8 | 202.3 | 199.0 | 112.9 | 110.3 | 128.6 | 92.6 | 140.5 | 145.8 | 111.5 | 78.3 | 84.3 | 80.7 | 104.7 |
| 8 | 198.6 | 203 | 200.9 | 201.7 | 200.8 | 115.6 | 114 | 131.2 | 96.1 | 145.1 | 157.7 | 114.7 | 81.8 | 84.3 | 81.2 | 105.6 |
| | 201.7 | 203 | 200.6 | 201 | 201.8 | 118.1 | 116.7 | 133.7 | 99.8 | 149.6 | 169.2 | 117.6 | 81.4 | 84.5 | 81.6 | 106 |
| 10 | 202.1 | 202.7 | 199.7 | 200 | 201.5 | 120.4 | 118.8 | 136.1 | 103.9 | 153.3 | 177.2 | 120.3 | 82 | 84.6 | 82 | 106.2 |
| | 201.6 | 202.6 | 199.6 | 199 | 201.3 | 122.5 | 120.2 | 138.9 | 108.1 | 158.5 | 183.4 | 122.5 | 83.3 | 84.8 | 82.4 | 106.5 |
| 12 | 201.3 | 202.5 | 199 | 198.1 | 200.9 | 124.7 | 121.6 | 141.2 | 112.2 | 161.8 | 187.5 | 124.8 | 84.9 | 85.2 | 82.9 | 106.8 |
| | 201.3 | 202.5 | 196.4 | 197.2 | 200.1 | 126.8 | 122.2 | 143.4 | 115.8 | 164.7 | 189.4 | 127 | 86.7 | 85.4 | 83.3 | 107 |
| 14 | 201 | 203.2 | 193 | 196.1 | 199.1 | 128.7 | 122.7 | 145.3 | 119 | 167.6 | 190 | 129.6 | 88.9 | 85.8 | 83.7 | 107.3 |
| | 200.2 | 203.5 | 190.7 | 194.8 | 198.1 | 130.3 | 123.2 | 147.2 | 121.9 | 169.8 | 189.8 | 132.3 | 91.3 | 86 | 84 | 107.3 |
| 16 | 200 | 203.6 | 189 | 193.2 | 197.5 | 132 | 123.8 | 148.8 | 124.5 | 172.3 | 188.2 | 135.3 | 93.8 | 86.5 | 84.4 | 107.4 |
| | 200.3 | 204 | 187.2 | 191.8 | 197.2 | 133.8 | 124.4 | 150.2 | 127 | 174.3 | 186.4 | 138 | 96.1 | 86.9 | 84.5 | 107.4 |
| 18 | 199.9 | 204.1 | 186.8 | 190.9 | 196.9 | 135.8 | 125.3 | 151.3 | 129.2 | 176.1 | 185.3 | 140.5 | 98.3 | 87.2 | 84.8 | 107.9 |
| | 199.7 | 203.5 | 186.6 | 189.7 | 196.6 | 137.7 | 126.6 | 152 | 131.4 | 178.1 | 185 | 141.7 | 100.5 | 87.4 | 85 | 108.4 |
| 20 | 199.8 | 202.9 | 185.6 | 188.5 | 196.1 | 139.5 | 128.5 | 152.6 | 133.3 | 180.8 | 184.6 | 142.5 | 102.3 | 88.3 | 85.1 | 108.8 |
| | 199.4 | 201.4 | 185.2 | 187.4 | 195.3 | 141.2 | 130.5 | 153.3 | 135.1 | 182.5 | 184 | 143.1 | 104.2 | 88.7 | 85.2 | 109.5 |
| 22 | 199.2 | 199.3 | 184.7 | 186.4 | 194.4 | 142.6 | 133.5 | 153.9 | 136.8 | 184 | 183.3 | 143.7 | 105.9 | 89 | 85.3 | 109.9 |
| | 199.6 | 196.9 | 184.2 | 185.5 | 193.6 | 143.8 | 136.4 | 154.5 | 138.3 | 185.1 | 182.6 | 144.2 | 107.6 | 89.4 | 85.4 | 110.5 |
| 24 | 199 | 194.6 | 184.1 | 184.5 | 192.6 | 144.9 | 139.7 | 155 | 139.8 | 186.1 | 181.8 | 144.6 | 109.2 | 89.9 | 85.5 | 111.1 |
| | 198.2 | 192.9 | 183.7 | 183.7 | 191.6 | 145.9 | 142.1 | 155.5 | 141.3 | 186.7 | 181.2 | 145 | 110.7 | 90.2 | 85.6 | 111.4 |
| 26 | 197 | 191.4 | 183.4 | 182.8 | 190.6 | 146.8 | 143.7 | 156.1 | 142.7 | 186.9 | 180.6 | 145.3 | 112.1 | 90.3 | 85.6 | 111.6 |
| | 195.9 | 190.1 | 183 | 182 | 189.7 | 147.7 | 148.1 | 156.6 | 144 | 187.2 | 180.1 | 145.6 | 113.7 | 91.1 | 85.6 | 112.2 |
| 28 | 195.1 | 189 | 182.5 | 181.2 | 188.9 | 148.6 | 150.7 | 157.2 | 145.3 | 187.4 | 179.7 | 146 | 115.3 | 91.2 | 85.7 | 112.4 |
| | 194.6 | 187.9 | 181.9 | 180.6 | 188.1 | 149.5 | 152.3 | 157.7 | 146.6 | 187.7 | 179.2 | 146.4 | 116.8 | 91.6 | 85.7 | 112.3 |
| 30 | 194.7 | 186.9 | 181.3 | 180 | 187.6 | 150.3 | 153.6 | 158 | 147.9 | 187.9 | 178.8 | 146.8 | 117.7 | 91.9 | 85.6 | 112 |

ambient=79.7

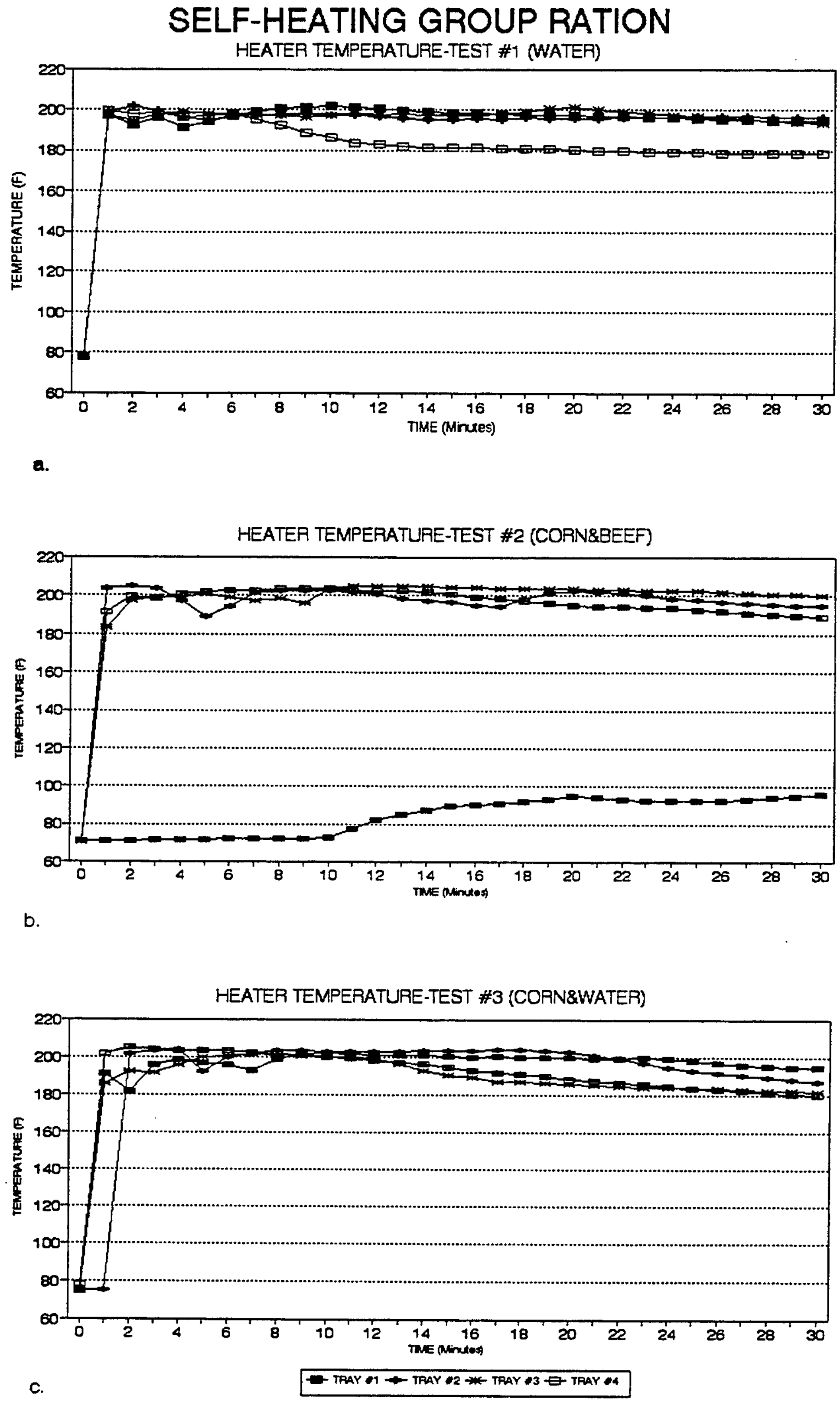



Figure 8: SHGR heater temperatures for each tray for experiments 1, 2 and 3.

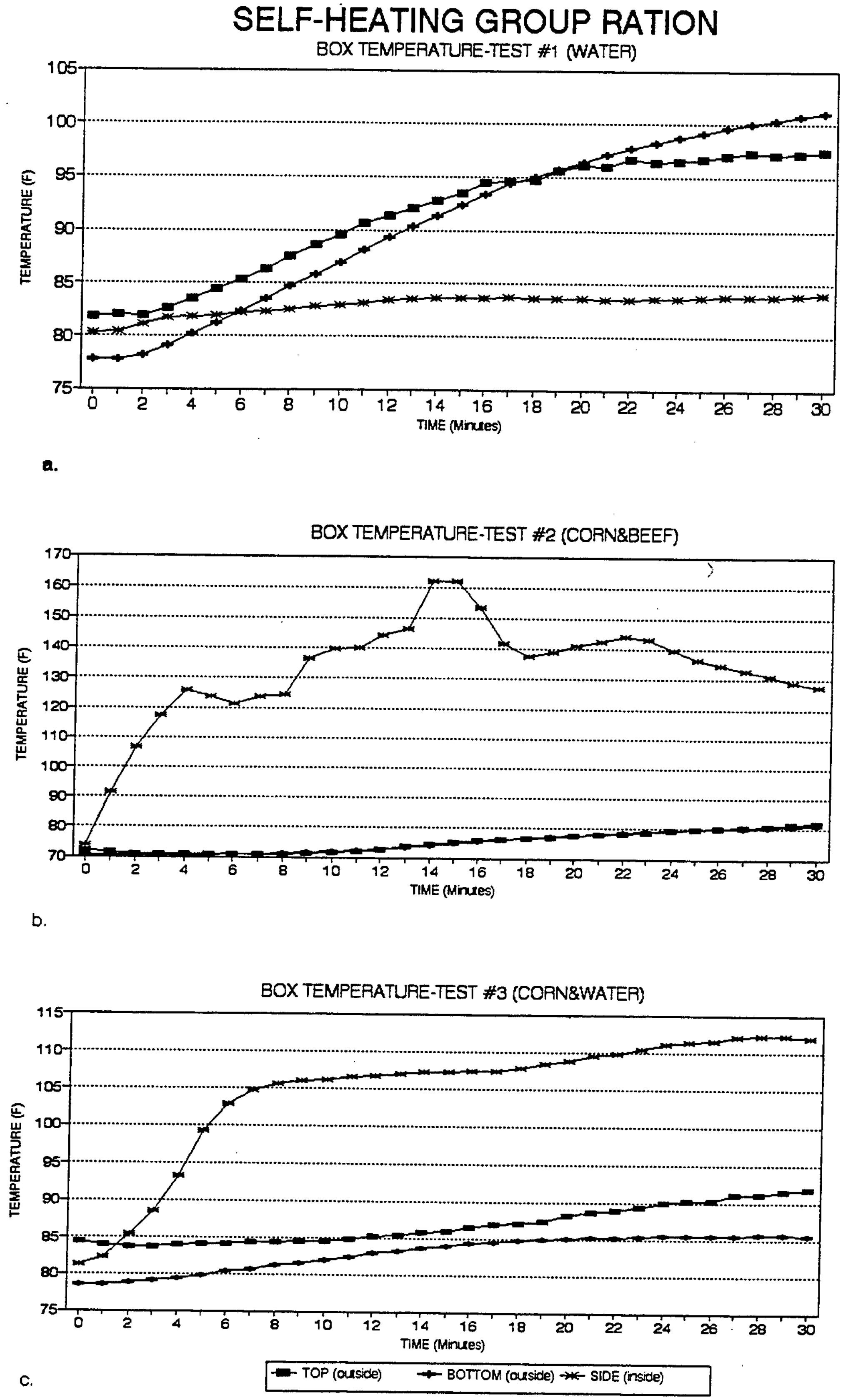



Figure 9: SHGR outside and inside box temperatures for experiments 1, 2 and 3.

Density (p) - lb/ft

air - 0.916
water - 62.4
corn - 47.1
beef stew - 51
polypropylene tray - 56.18
Styrofoam - 2.0
fiberboard - 21.5
tri-laminate pouch - 137.3
flameless ration heater - 81.15
stainless steel - 488

Area - (A) - ft

water - 0.9
corn - 0.9
beef stew - 0.9
polypropylene tray - 0.9
Styrofoam - 0.9
fiberboard - 0.9
tri-laminate pouch - 0.9
flameless ration heaters - 0.556

Width of items (w) - ft

water - 0.1175
corn - 0.1557
beef stew - 0.1557
polypropylene tray - 0.0031
Styrofoam - .0417
fiberboard - 0.0104
tri-laminate pouch - 0.0003
flameless ration heater - 0.0259

Note: The width of the food items was calculated from the density, area and mass of the pouch and compared with the physical measurements. There was a small difference in the measured and calculated dimensions of the food, but the model calculations used the calculated width of the food pouch.

Single dimension models are usually developed for symmetric objects with equal sized contact areas. However, this model does allow for different sized contact areas between materials. The results are not as accurate as a two-dimensional model, but better than the usual single dimensions FDM models when the contact areas aren't equal. For the SHGR only the heater area was different from the other contact areas.

The bottom three trays in the model used the average temperature of the three FRHs (one FRH in each tray), since the temperatures of the FRHs were similar and there were not enough thermocouples for all the FRH pads. The top tray was modeled using the temperatures from only the top tray from the three experiments.

The first model developed was a 12 node model, but the 12 nodes didn't accurately model the SHGR (the temperatures didn't rise quickly enough). So the number of nodes for the model was increased to 30 and finally to 46 nodes. The results of the 46 node model and the 30 node model were close so additional nodes were not added. The temperatures generated from the 46 node model were similar to most of the experimental results for the bottom three trays. Yet for the top tray and trays that had water for food, there was a large disparity between the model and experimental results that required an additional effort to simulate the heat transfer.

Verification of FDM Model with Experiment 1

Figure 10 gives the results from experiment 1 plotted against the 46 node FDM model. In pouch #1 (water) node 13 was the node that corresponds to the location of the thermocouple (see Figure 1). However, node 13 from the FDM model did not agree with the experimental result. Therefore a second simulation was run for tray #1 with the heater area increased by 20% to compensate for diffusion of heat along the fiberboard container of the FRH. The result of the second simulation is shown as 0.67AREA. The 0.67AREA line is closer to the experimental results, but still not adequate.

The faster heating primarily occurred because of convective currents in the water as mentioned in S.G. Kandilar[1]. Yet the added FRH area was not adequate in this model to compensate for the convective currents occurring in the water. Professor Kandlikar did not use water in the MRE package for model verification for this very reason. However, other adjustments to the FDM model are tried here to predict or simulate the heat transfer in heated water within the SHGR because of the convenience of water for experimental testing.

Tray #2 in Figure 10 was modeled with node 23 and the model heater area was increased to 0.9 $ft^2$ (the same size as the food pouches). The result of the increased heater area was closer to the experimental result than the second model line, where the thermal conductivity of the water was increased to 0.75 Btu/h*ft*°F. Still neither method agreed well with the experimental result except for the final temperature of the experiment.

In tray #3, both the heater area and thermal conductivity of the water were changed in the model. Node number 33 corresponded to the location of the thermocouple in the third tray. Using node 33 with the heater area equal in size to the food pouch area and the thermal conductivity of the water increased to 0.56 Btu/h*ft*°F gave the best fit. Note that in Figure 10 the center temperatures of the first three trays' experimental results were very close, as shown in Figure 5.

# SELF-HEATING GROUP RATION - TEST #1

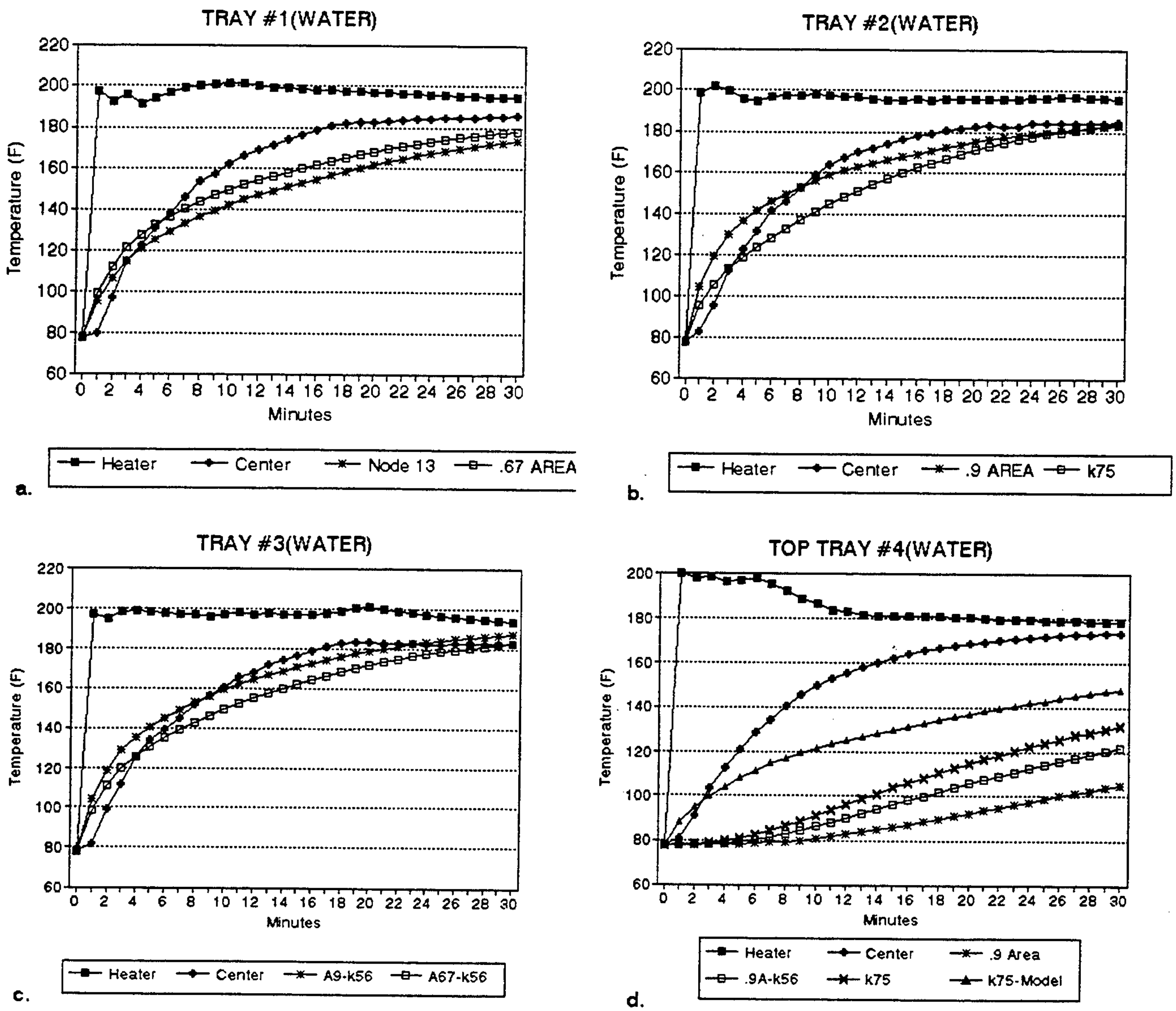



Figure 10: Tray #1, #2, #3 and #4 of the SHGR from experiment 1 compared against the FDM model.

Therefore the methods used to match the model to the experimental results were shown for only one of the first three trays so the other methods attempted for modeling the experimental results could be shown.

The top tray in the SHGR was heated significantly more than the conduction model could predict, even after trying the methods used for the bottom three trays. These results strongly indicate another form of heating taking place within the SHGR. In Kandlikar's[1] work he found the MRE was also being heated by condensing steam on the top side of the MRE. This seemed to also be the type of heat transfer mechanism occurring within the SHGR. To apply a convective boundary condition, further experimentations and models would need to be developed that were not possible during this project. However, a proposal was submitted to investigate the additional heat transfer mechanism.

Verification of FDM Model with Experiment 2

Figure 11 is the results from experiment 2 plotted against the model. In experiment 2 the area for the heater was reduced to 0.556 $ft^2$. In Figure 11 node 13 (where the thermocouple was located) exceeded the temperature of the corn, unlike experiment 1 where node 13 underestimated the temperature of the water. The problem may have been the thermal conductivity of the corn used from a book was too high or because the small piece of fiberboard over the thermocouple provided too large of a temperature shield. The fiberboard had been placed over the thermocouple's to shield them from direct heat from the FRHs so the temperature recorded would more accurately represent the food temperature. Mr. Peter Lavigne's testing had shown the thermocouple with a piece of fiberboard on top had corresponded closely to the food temperatures at the end of the experiment. Therefore a model line representing the average of the nodes in the food was graphed in Figure 11. The model line representation of the experimental results was good and accepted as an accurate representation for the food.

Tray #4 in the experiment again exceeded the model's predicted results. The model was approximately 30°F lower than the experimental results. Node 43 like node 13 was located on the top of the food pouch where the thermocouple was located. However, node 43 underestimated the food temperature, indicating the food pouch was heated from the top side too.

# SELF-HEATING GROUP RATION - TEST #2

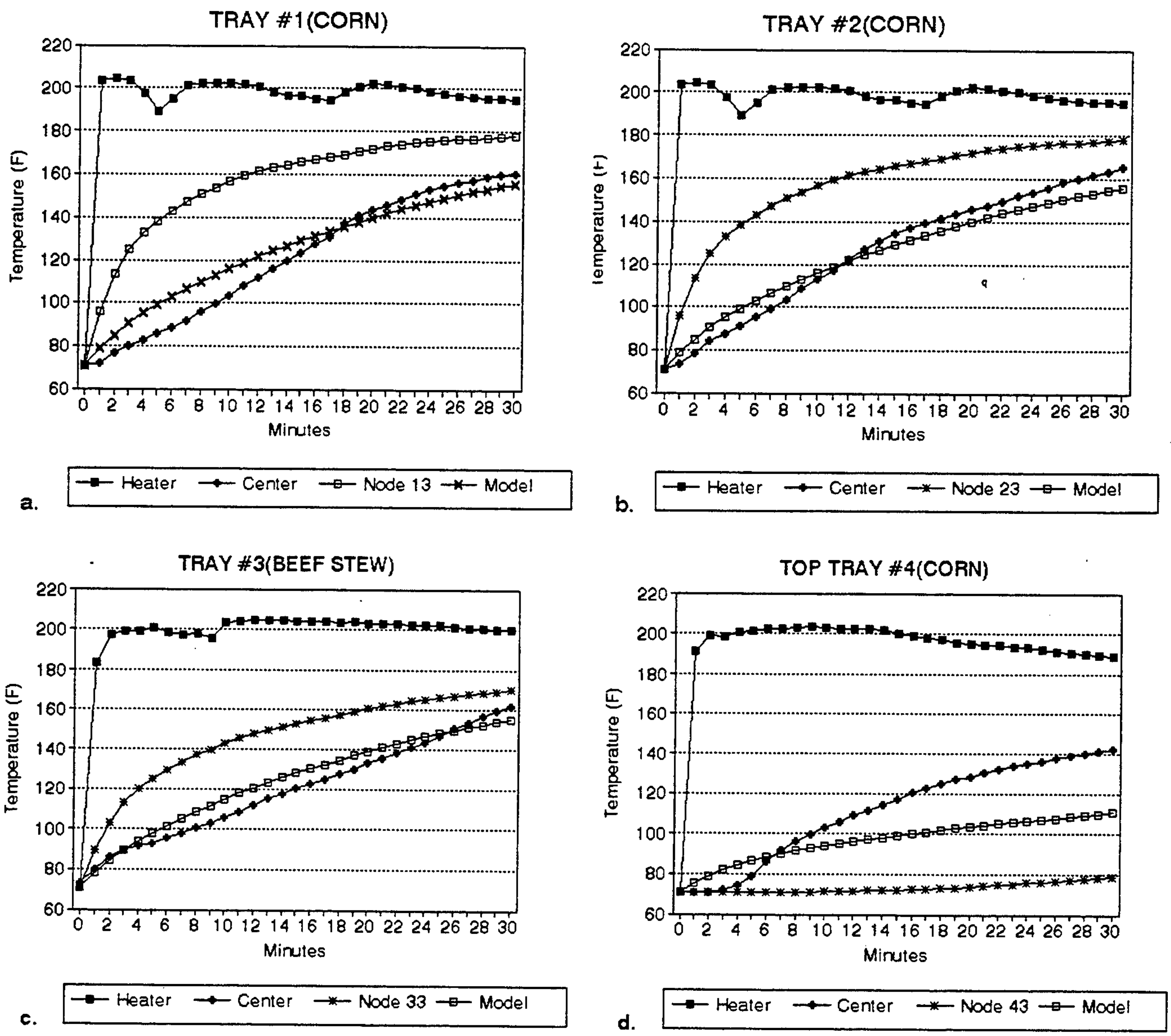



Figure 11: Tray #1, #2, #3, and #4 of the SHGR from experiment 2 compared against the FDM model.

## Verification of FDM Model with Experiment 3

Figure 12 is the results from experiment 3 plotted against the FDM model. In tray #1 the model line was again an accurate representation of the experimental results. However, in tray #2 the model underestimated the experimental result, although the final temperature was close. The experimental results seem to indicate the second tray gained more heat as a result of having water in the third pouch as food rather than corn.

The third tray with water was represented accurately again, as in experiment 1 with node 33 when the heater area and thermal conductivity were increased (heater area equal to 0.9 $ft^2$ and thermal conductivity increased to 0.56 Btu/h*$ft^2$). The model line for this configuration is also quite close to the experimental result. Tray #4 with corn was again warmer than the model could predict.

## Results of FDM Model Verification

More experiments were needed for complete verification, but were not possible because of the lack of heaters and trays. However, the FDM model's predictions of the heat transfer within the SHGR were considered accurate for the first three trays of food for the experiments performed (i.e., experiment 2 & 3). The top tray #4 was not verified and requires an additional heat transfer mechanism to account for the more rapid heating. For modeling the heating of water in the SHGR, the added heater area and increased thermal conductivity (to simulate convective heat transfer) seemed to provide the best solution. For modeling different foods within the SHGR the average of the 10 nodes in the food (the Model line) was best. Using this information and the thermal conductivity, specific heat, and density of potatoes and peas, a prediction of the time to heat was made in Figure 13.

In Figure 13 trays #1, #2, and #3 reach 160°F in approximately half the time (15 minutes). If the top tray of food was a dessert item or other entree that needed only to be slightly warmed, serving of the entrees could begin in half the time.

# FINITE ELEMENT METHOD

Most real-world engineering systems are often difficult, or impossible to solve with a closed-form mathematical solution. FEM is a numerical analysis that provides a convenient way of obtaining approximate solutions to almost any engineering problem. FEM is a very versatile and powerful numerical

# SELF-HEATING GROUP RATION - TEST #3

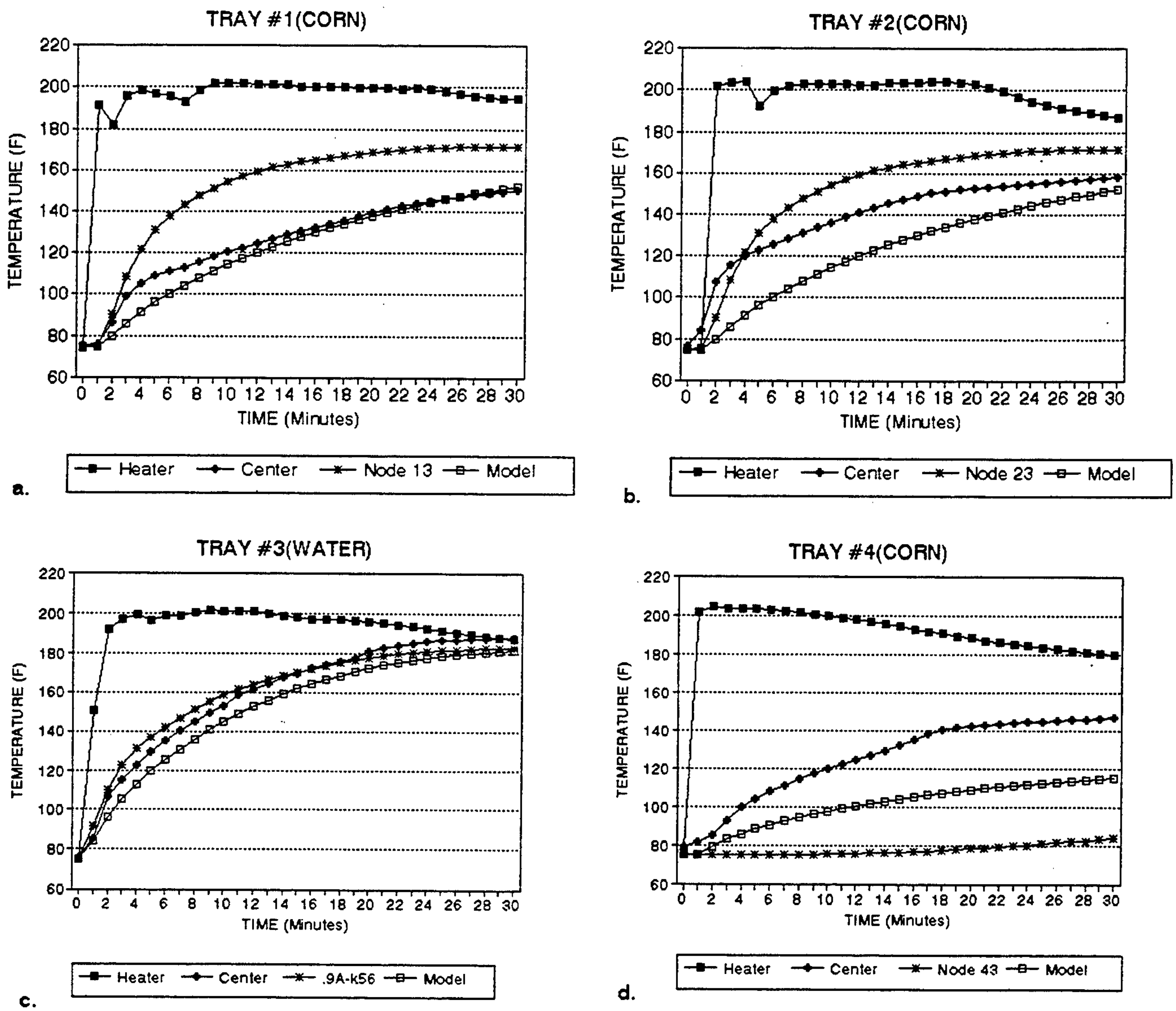



Figure 12: Tray #1, #2, #3 and #4 of the SHGR from experiment 3 compared against the FDM model.

# SELF-HEATING GROUP RATION

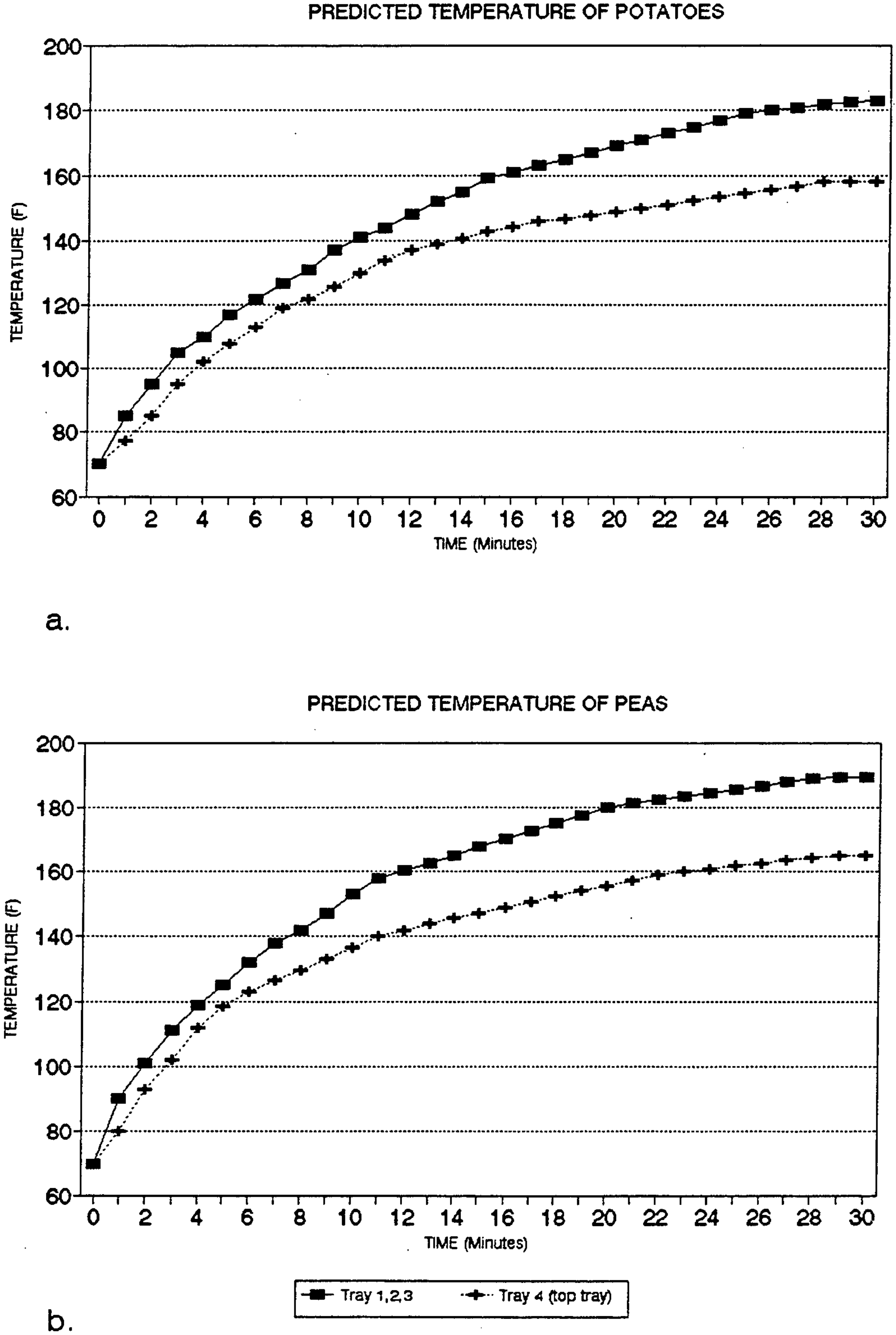



Figure 13: FDM model prediction of the temperature of potatoes when heated in the SHGR.

technique that has several advantages over the FDM. With FEM it's possible to write a program that can solve a variety of heat transfer problems. A general FDM program that can solve the same class of problems would be impractical to write. Irregularly shaped boundaries and mixed boundary conditions pose no particular problem with the FEM, but are extremely difficult for the FDM.

The solutions from FEM enable the optimization of materials to be analyzed, which can result in savings of material cost, shipping cost (on high volume items) and waste reduction. Still, serious consideration must be given to the real economics and subsequent cost in the optimization of a design.

The FEM code used to develop this model was the ANSYS-PC Thermal Module version 4.4A, developed by Swanson Analysis Systems Inc. The code can solve conduction, convection, radiation, and phase change problems. The models developed in ANSYS can be up to three-dimensions and solved as steady state or time-dependant analysis.

## FINITE ELEMENT METHOD VERIFICATION

As a result of the symmetry the SHGR was modeled as a two-dimensional model using only one-half of the cross-section of the SHGR. The physical constants listed in the "Finite Difference Model Verification" section were again used in the FEM verification. Approximately 10 minute intervals for the FRH's temperatures were specified for the ANSYS model. Between the specified temperatures, a ramp loading condition was applied to approximate the FRH's temperature curve. Ramp loads are applied by linearly interpolating the loads between specified loads. The other type of load condition is step loads, step loading conditions are constant loads until the next load condition is applied.

The initial temperature of the SHGR was specified at the experimental temperatures as a uniform temperature condition. The bottom side of the SHGR was a conduction boundary condition with the SHGR resting on stainless steel at room temperature. Note the bottom boundary is a result of the Experimental Set up and is not likely to be the actual boundary condition. The other side conditions were specified as a constant temperature convective boundary condition. The average ambient temperature for the experiment was specified at the same temperature as the initial temperature applied to the SHGR. The convective heat transfer coefficient ($h_c$) was set low (2 Btu/h-ft$^2$-°F) to simulate still air. The interior boundary condition of the SHIGR model was assumed as conduction.

The first model developed for the SHGR had similar problems as the first model for the FDM method. The FEM model did not have enough nodes and elements to model the experimental results. Yet, the FEM model responded too quickly to the FRHs whereas the FDM model responded too slowly. There was also a problem with the top Styrofoam and fiberboard not heating. To fix the model the Styrofoam and fiberboard areas were redrawn and the whole model was remeshed with more nodes and elements. The resulting model contained 2216 elements, 2090 nodes. The new solution yielded the following results.

Verification of FEM Model with Experiment 1

In comparing the FEM model with the experimental results the author picked a node that was in approximately the same location as the thermocouples were during the experiment. In Figure 14 where water was used in the food pouch, the ANSYS results were very similar for tray #1, #2, and #3. For tray #4 the ANSYS model under-estimated the edge temperature of the water, but was very close on the center temperature. The FEM model was more accurate modeling the water in the SHGR than the FDM model. Note the FEM model used the actual thermal conductivity of water) 0.375 Btu/h*ft*°F, whereas various thermal conductivities for the water were used for the FDM model to match the experimental results.

Verification of FEM Model with Experiment 2

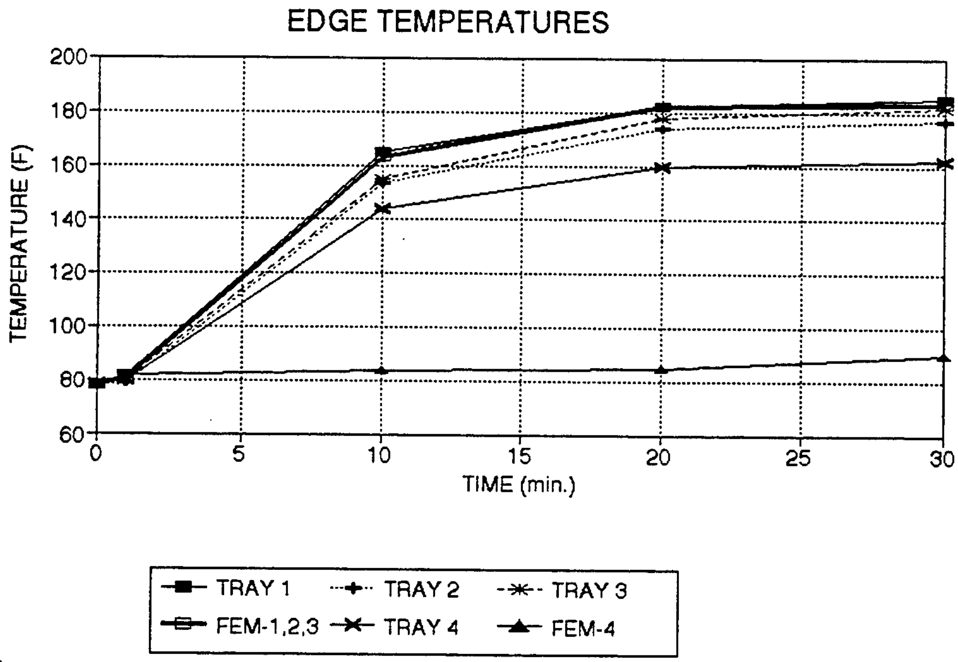
Figure 15 has the results of experiment 2 compared against the ANSYS results. The results for tray #3 that contained beef stew were very good; however, the trays containing corn were significantly cooler near the edges in the ANSYS model than in the experimental results. The top tray also showed a large disparity between experimental and model results. These results also suggest that tray #4 is being heated by other means.

Verification of FEM Model with Experiment 3

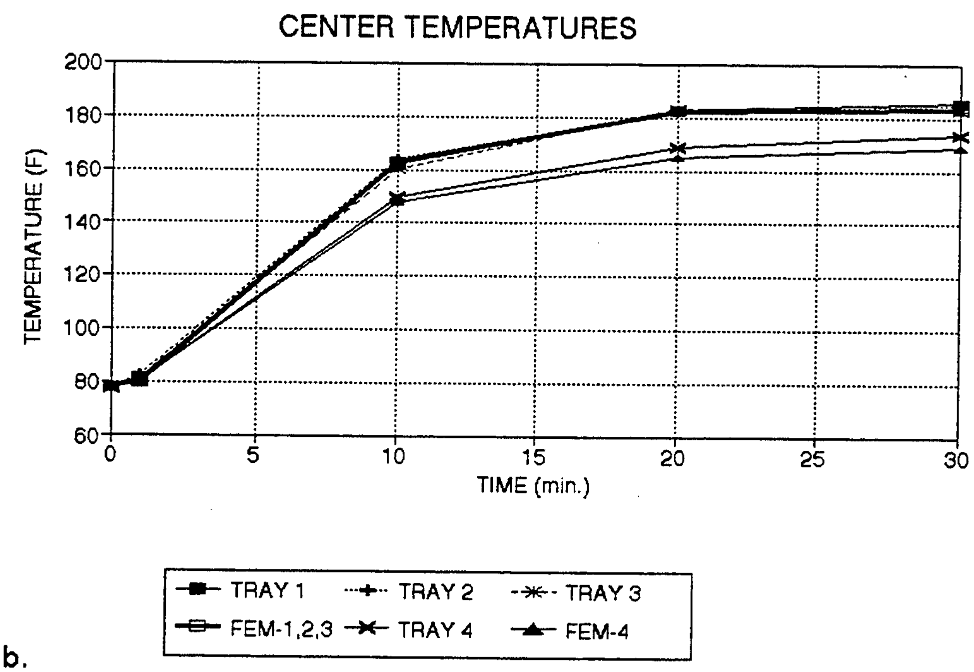
The results for experiment 3 (Figure 16) are similar to experiment 2 except for the third tray where water was used in the food pouch. The FEM results for the third tray are not as accurate as experiment 1, where water was used in all four trays. The ANSYS model's center temperature for the water indicates that heat from the water would be lost to heat the corn; however, the experiments did not confirm that occurrence.

# SELF-HEATING GROUP RATION

## FEM - VERIFICATION FOR TEST #1




a.




b.

Figure 14: SHGR for experiment 1 compared against the ANSYS model (all four trays contained water) all three trays contain water.

# SELF-HEATING GROUP RATION

## FEM - VERIFICATION FOR TEST #2

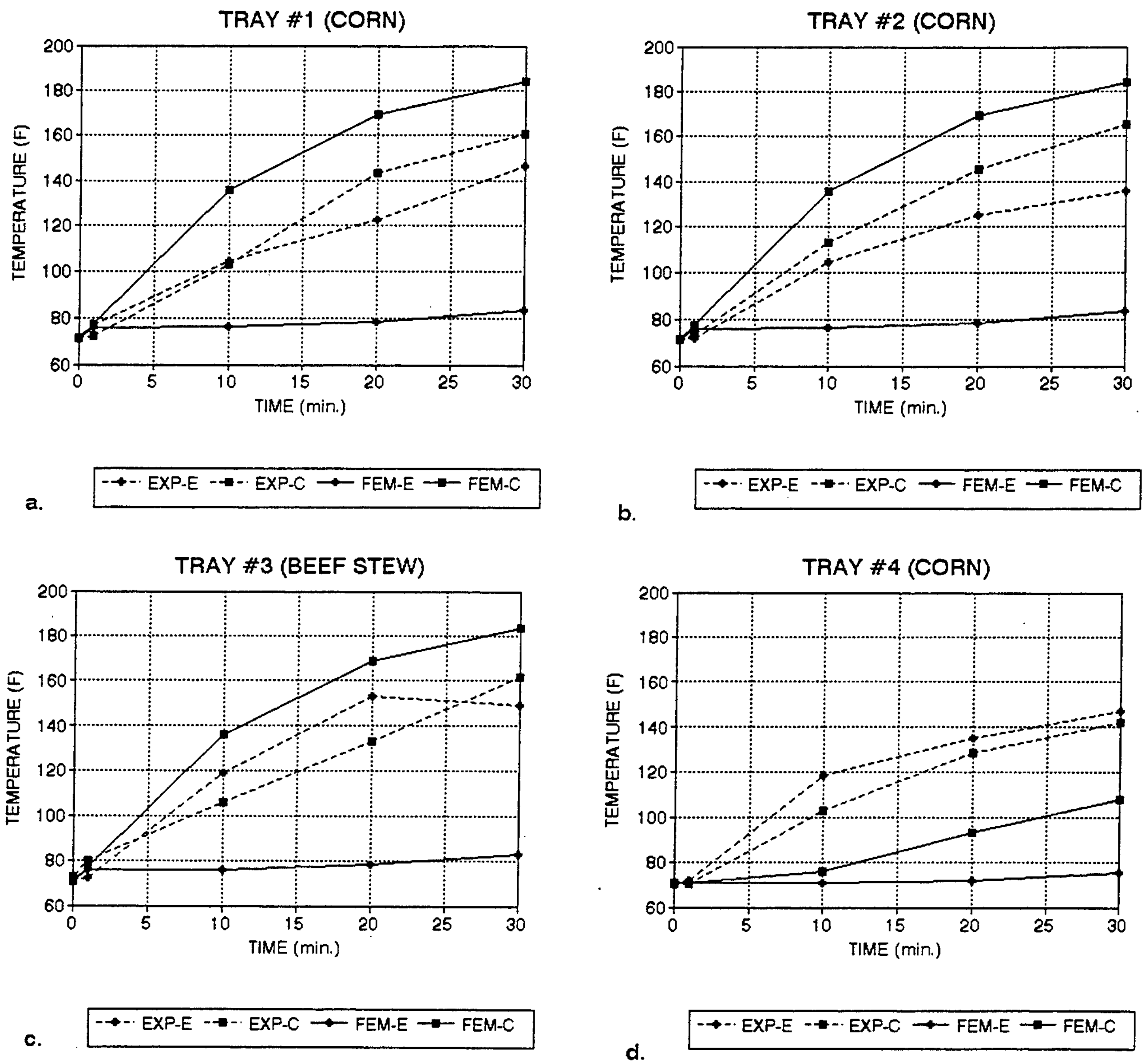



Figure 15: SHGR for experiment 2 compared against the ANSYS model. All trays contain corn except tray #3 contains beef stew. "EXP-E" is the experimental results for the edge of the tray and "FEM-C" is the finite element method results for the center of the tray etc.

# SELF-HEATING GROUP RATION

## FEM - VERIFICATION FOR TEST #3

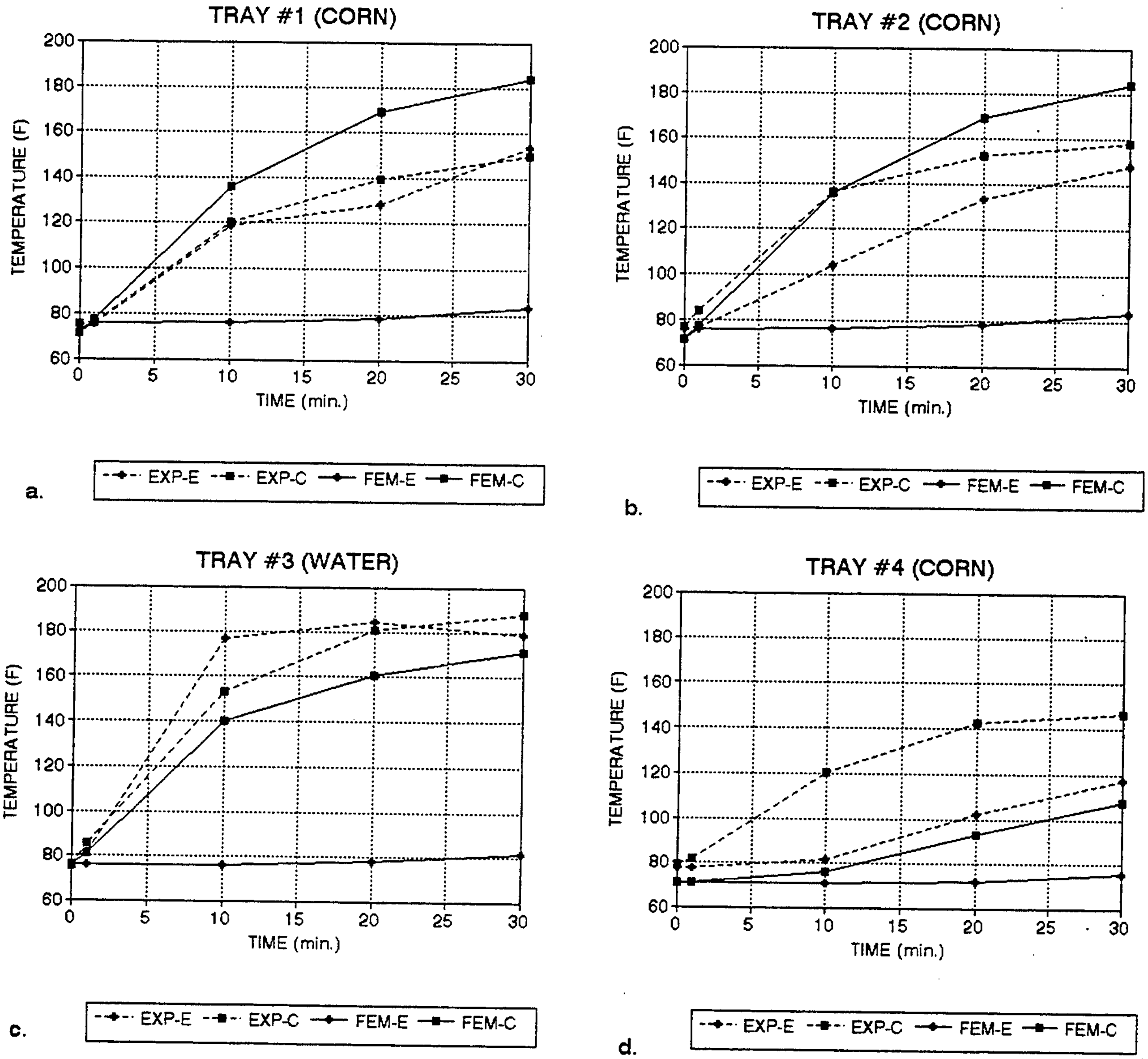



Figure 16: SHGR for experiment 3 compared against the ANSYS model. All trays contain corn except tray #3 contains water. "EXP-E" is the experiment results for the edge of the tray and "FEM-C" is the finite element method results for the center

## Results of FEM Model Verification

Although the results of the FEM model verification for the SHGR were better for the experiment with water in the pouches, the SHGR configuration from experiment 3 with water and corn was used to conduct further analysis on the SHGR. Due to time constraints, verification of the FEM model was not completed.

It appeared that the thermal conductivity of the corn and heater area may also have needed adjustment as did the FDM model. Besides the need to adjust the SHGR FEM model for the experiments with corn, the desire also existed for more experimental tests to have a solid baseline. As mentioned earlier, additional experimental testing was not possible because of the lack of heaters and trays. The FEM model results of water in the SHGR were the most accurate. Results from this modeling effort are not considered completely reliable but will be used primarily in comparing model against model to determine the best SHGR configuration.

## COMPARISON OF THE FDM TO FEM MODEL

In the first experiment the FEM was better than the FDM in modeling the temperature change in the water. However, both models were unable to model the experimental temperature of the fourth tray of water. Both the FEM and FDM models did poorly at predicting the temperature of the corn in the second experiment. The models in experiment 2 both predicted a higher temperature for the corn. The results of the FEM and FDM model in experiment 2 were closer to each other than they were to the experimental temperature of the corn. However, the edges or ends of the pouches of corn were significantly warmer than the FEM model could predict.

The same experimental results occurred for the third experiment as the second experiment except for the third pouch that was filled with water. The FEM model results in experiment 3 underestimated the temperature of the water. This was especially interesting for the FEM model since it had accurately modeled water in the first experiment. The FEM model showed a difference in heating the water when heated with the corn; the experimental results did not show any difference.

This last observation may also point to the fact of heaters varying in their output and the efficiency of the water delivery system to properly activate the heaters. In retrospect, it may have been wiser to verify the models using a known heat source, such as a frying pan to heat the food pouches. In this type of a configuration more thermocouples would be available for the food pouch and the results would be more repeatable.

## FEM MODEL RESULTS FOR THE SHGR

The top graph, Figure 17 shows the results of the FEM model that predict the top side temperature of the SHGR at 10, 20 and 30 minutes. The temperature varied enough from center to edge in the model's results to conclude the experimental setup (with only one thermocouple on the top and bottom) wasn't adequate to verify the results. The use of an infrared imager would have provided a means to verify the model's results. In the Figure the FEM temperatures were higher than the experimental results.

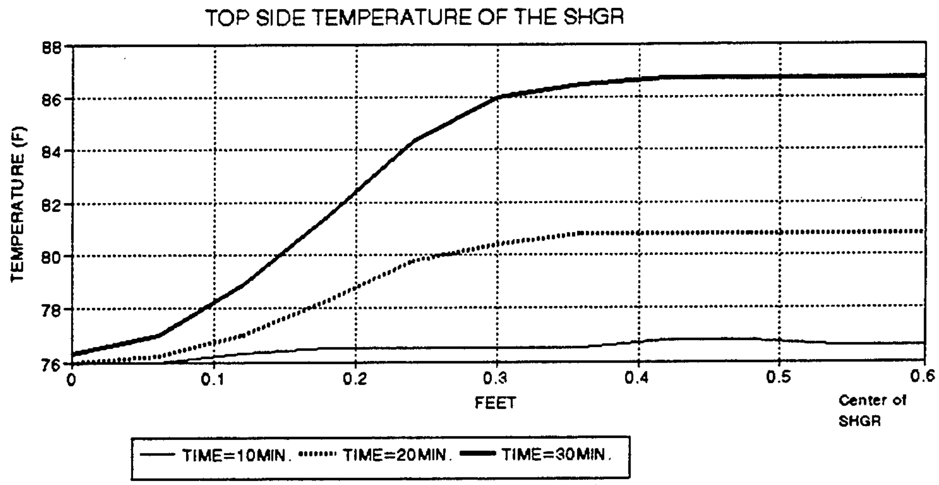
The middle graph in Figure 17 shows the results of the FEM model's prediction for the left side temperature of the SHGR at 10, 20 and 30 minutes. The left side temperature wasn't recorded in the experimental results. The side temperature taken in the experiments was inside the fiberboard container of the SHGR. The FEM model's predicted temperature changes for the left side were very small, since the model predicted rather cool edges or ends for the food pouches. The left side was likely warmer than shown in Figure 17 since the food near the edge during the experiment was warmer than the ANSYS model predicted. Yet the left side losses were likely less than either the top or bottom side.

The bottom side temperature of the SHGR at 10, 20, and 30 minutes, shown in the lower graph of Figure 17 also predicted warmer temperatures and therefore greater heat loss. As before, the temperature near the edge or ends of the SHGR may have been higher than the model predicted since the experimental values for the food near the edge were higher than the model predicted.

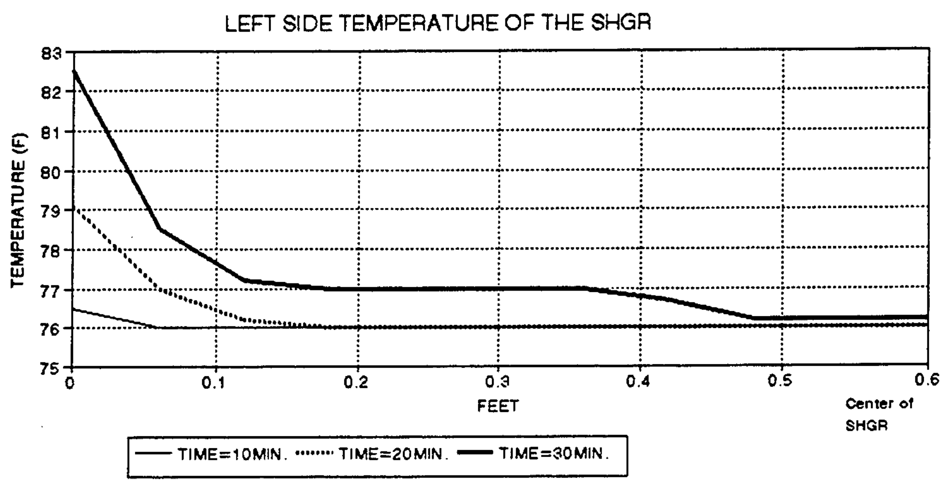
In Figure 18 the FEM model predicted the overall temperature of the SHGR at 10, 20 and 30 minutes. The FEM model's predicted temperature in each pouch of food varied more from center to edge than the experimental results. The convective currents generated in heating the water often equalize the temperature throughout the water. Still, the results of the FEM model revealed the advantage of having chemical heating pads that cover the full size of the trays. As mentioned previously full-size chemical heating pads are planned for the SHGR but were not available for the experimental testing.

### Heat Lost from the Standard SHGR

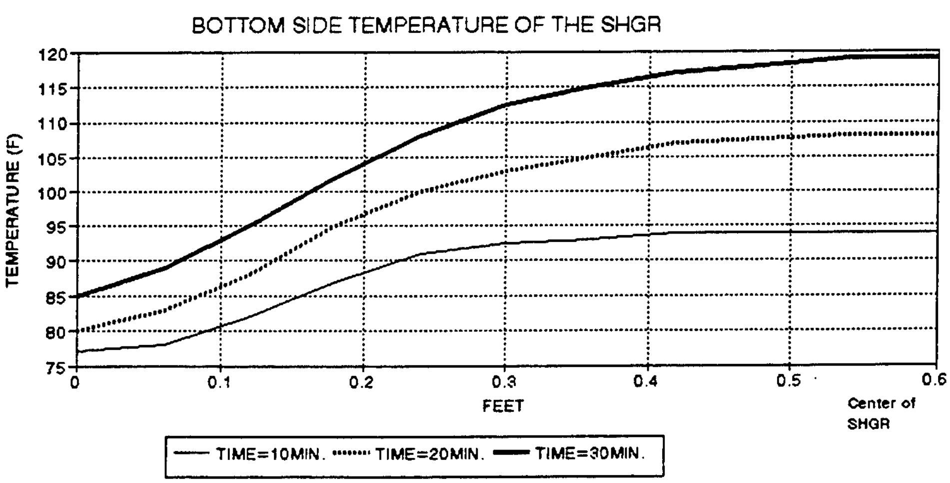
Figures 19, 20, and 21 are the results from the FEM model that predicted the heat flow (q) and heat flux (q") from the SHGR at 10, 20 and 30 minutes for the top, left bottom side respectively. In the figures the FLOW lines are the heat flow and the FLUX lines are the heat flux. Heat flow is the rate of heat transfer per unit of depth (Btu/h-ft) of the SHGR. Heat flow's standard units are Btu/h, but since this model is only a two-dimensional the third dimension (depth) is accounted for by




a.

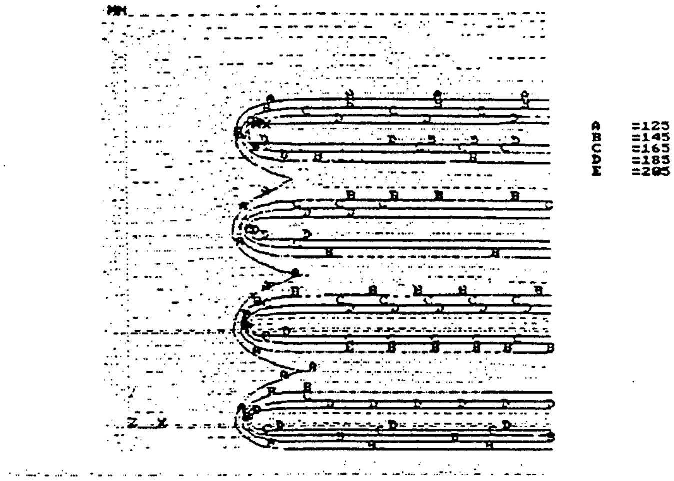



b.

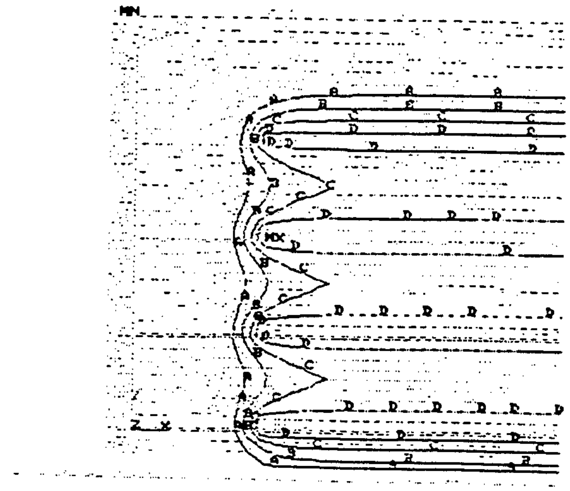



c.

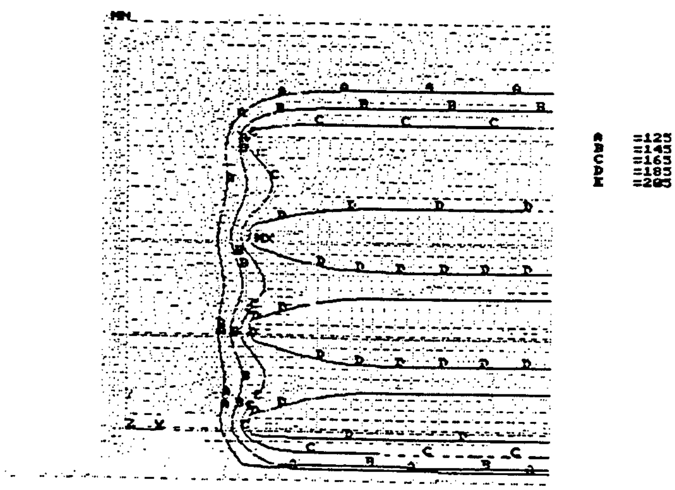
Figure 17: Temperature along the sides of the SHGR at 10, 20 and 30 minutes.




a. SHGR at 10 minutes.

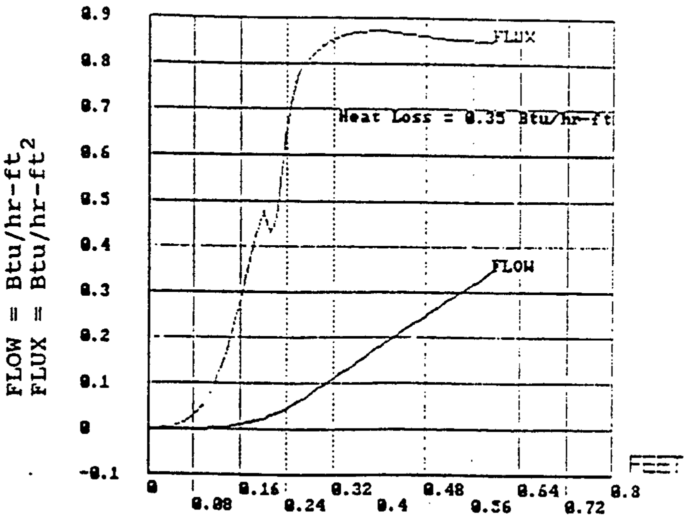


b. SHGR at 20 minutes.

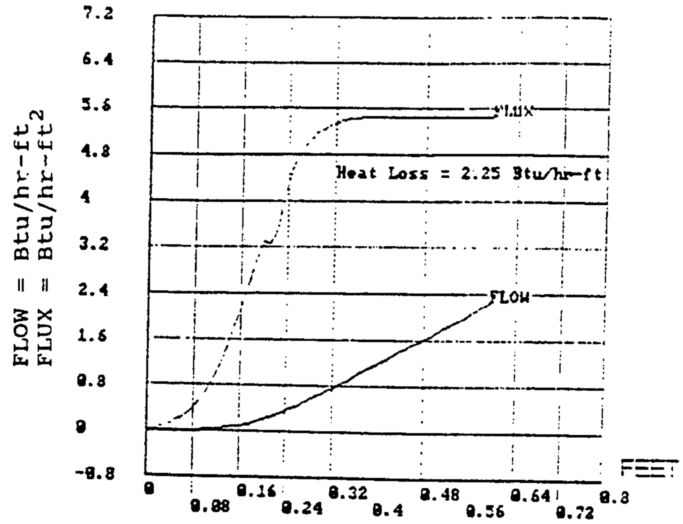



c. SHGR at 30 minutes.

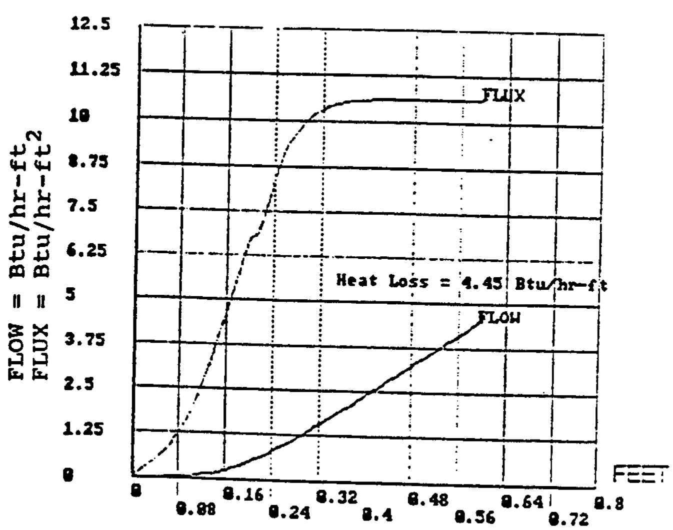
Figure 18: SHGR temperatures with corn and water in the third tray at 10, 20 and 30 minutes.




a. Top side heat loss at 10 minutes. Center of SHGR




b. Top side heat loss at 20 minutes. Center of SHGR




c. Top side heat loss at 30 minutes. Center of SHGR

Figure 19: Heat flow (q) and heat flux (q") for the Top Side of the SHGR at 10, 20, and 30 minutes.

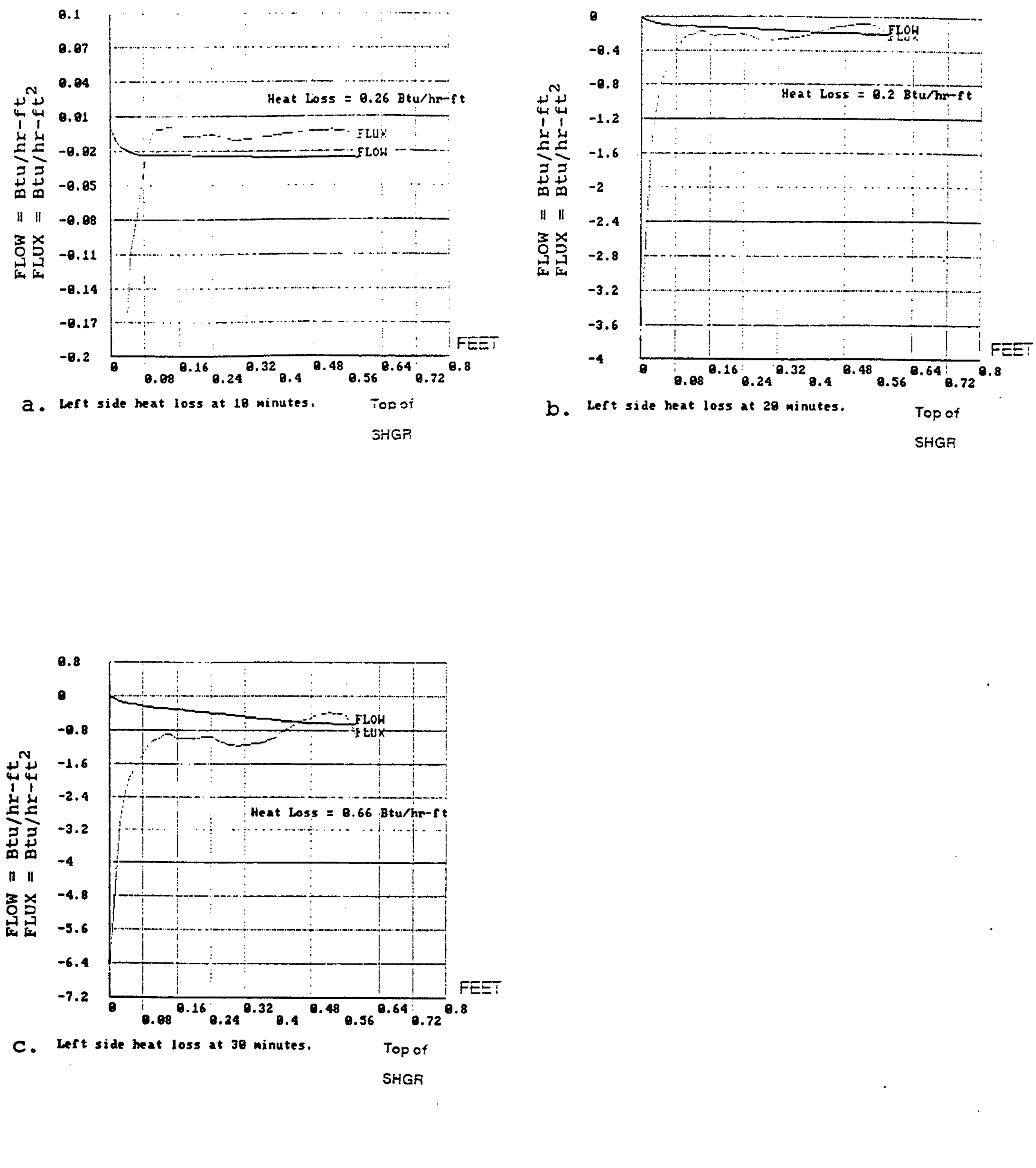
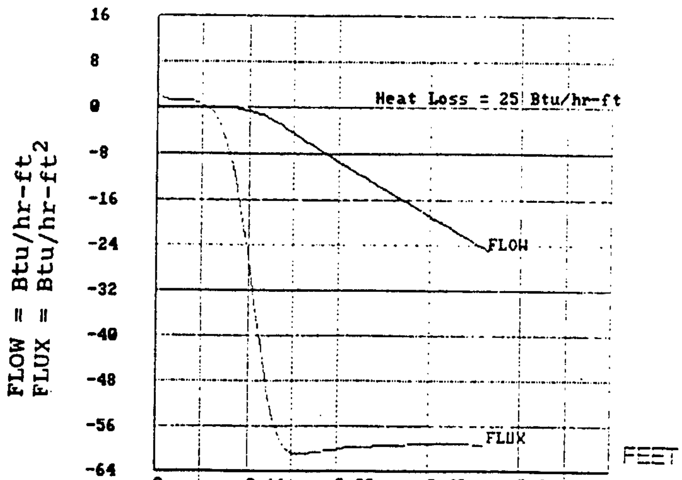
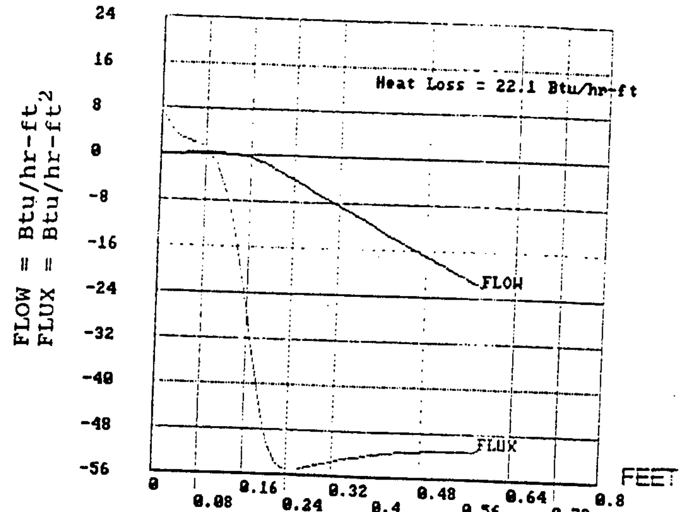


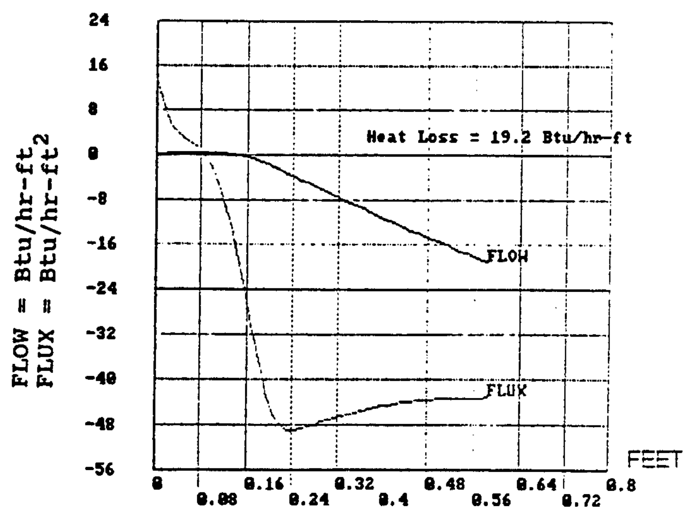

Figure 20: Heat flow (q) and heat flux (q") for the Left Side of the SHGR at 10, 20, and 30 minutes.




a. Bottom side heat loss at 10 minutes, Center of SHGR




b. Bottom side heat loss at 20 minutes, Center of SHGR




c. Bottom side heat loss at 30 minutes, Center of SHGR

Figure 21: Heat flow (q) and heat flux (q") for the Bottom Side of the SHGR at 10, 20, and 30 minutes.

multiplying heat flow times the depth (assuming uniform heat loss). The heat flow also must be multiplied by two because the model is half of the cross-section. Heat flux is heat flow per unit area (Btu/h-ft$^2$), but again to account for the third dimension the units are Btu/h-ft$^3$. Therefore, in these figures the heat FLOW line is the integral of the FLUX line, and the final end point of the FLOW line is the total heat flow from that surface (i.e., bottom, top and left side).

The heat loss calculation is only for the time during heating of the food. It doesn't account for any loss occurring after the 30 minutes when the food is being served. The heat lost from the bottom side is assumed to be primarily by conduction. The top and left side of the box lose heat by convection. The bulk air temperature around the SHGR was set to 76$^{o}$F, except for the final analysis where it was set to 80$^{o}$F.

In Figure 19 (the top side of SHGR) the heat flux and flow are positive because in ANSYS the sign is representing the direction of the flow with respect to the model axis rather than the fact the SHGR is losing heat. Therefore, if the right side had been used instead of the left side to determine the heat flux and flow, the values would have also been positive.

Since the heat flow varies with time, the total heat loss was calculated by integrating the heat flow at each time interval using Simpson's rule to get an estimate for the top, left and bottom sides total heat loss (Btu's) from the SHGR. The total heat loss from the top side using Simpson's rule was 0.80 Btu/linear ft, from the left side it was 0.13 Btu/linear ft and for the bottom side it was 9.45 Btu/linear ft The total heat loss for each side of the SHGR was as follows:

Top Side

0.80 Btu/ft * 2 (model symmetry) * 0.875 ft (depth)= 1.40 Btu

Left Side (All Vertical Sides)

0.13 Btu/ft * ((0.875 ft (depth)* 2) + (1.125 * 2)) = 0.52 Btu

Bottom Side

9.45 Btu/ft * 2 (model symmetry) * 0.875 ft (depth) = 16.54 Btu

The Total predicted heat loss from SHGR was:

1.40 Btu + 0.52 Btu + 16.54 Btu = <u>18.46</u> Btu

The bottom lost 90% of the total heat lost from the container. In an attempt to reduce the bottom heat loss a second FEM model using 1-inch styrofoam was modeled.

Results from 1 inch foam FEM Model

Shown in Figure 22 are the results of the FEM model that predict the bottom side temperature of the SHGR at 10, 20, and 30 minutes with 1-inch of Styrofoam. The results of the FEM model that predicted the top, and left side temperature of the SHGR at 10, 20, and 30 minutes with 1-inch Styrofoam were approximately the same as the standard SHGR with 1/2-inch of Styrofoam, so they are not shown. Figure 23 is the results of the FEM model that predict the complete temperature of the SHGR at 10, 20 and 30 minutes.

Analysis of SHGR with 1 inch of Styrofoam

In Figure 24 the results of the FEM model that predicted the heat flow (q) and heat flux (q") from the bottom side of the SHGR at 10, 20 and 30 minutes is shown. The results of the FEM model that predicted the heat flow (q) and heat flux (q") from the top, and left side of the SHGR at 10, 20 and 30 minutes were also approximately the same as the standard SHGR with 1/2-inch so they are not shown. Using Simpson's rule and integrating the heat flow at each time interval for the bottom side, the total heat flow (q) from the SHGR was estimated. The total heat flow from the top side using Simpson's rule was 0.79 Btu/linear ft from the left side it was 0.262 Btu/linear ft and 5.42 Btu/linear ft from the bottom side. The total heat loss for each side of the SHGR was as follows:

Top Side

0.79 Btu/ft * 2 (model symmetry) * 0.875 ft (depth) = 1.38 Btu

Left Side (All Vertical Sides)

0.262 Btu/ft * ((0.875 ft (depth) * 2) + (1.125 * 2)) = 1.05 Btu

Bottom Side

5.42 Btu/ft * 2 (model symmetry) * 0.875 ft (depth) = 9.48 Btu

The Total predicted heat loss from SHGR was:

1.38 Btu + 1.05 Btu + 9.48 Btu = 11.91 Btu

The bottom loss was 80% of the total heat loss from the SHGR container. The total heat loss was 35.5% less than the standard configurations total heat loss. Yet the total heat input to the SHGR was 2080 Btu, so the total convective heat loss was less than 1% of the total heat input. Since the heat loss was so low, another standard SHGR configuration with an initial temperature of 40$^{O}$F was modeled. This FEM model was to find the significance of the ambient temperature on the standard SHGR.

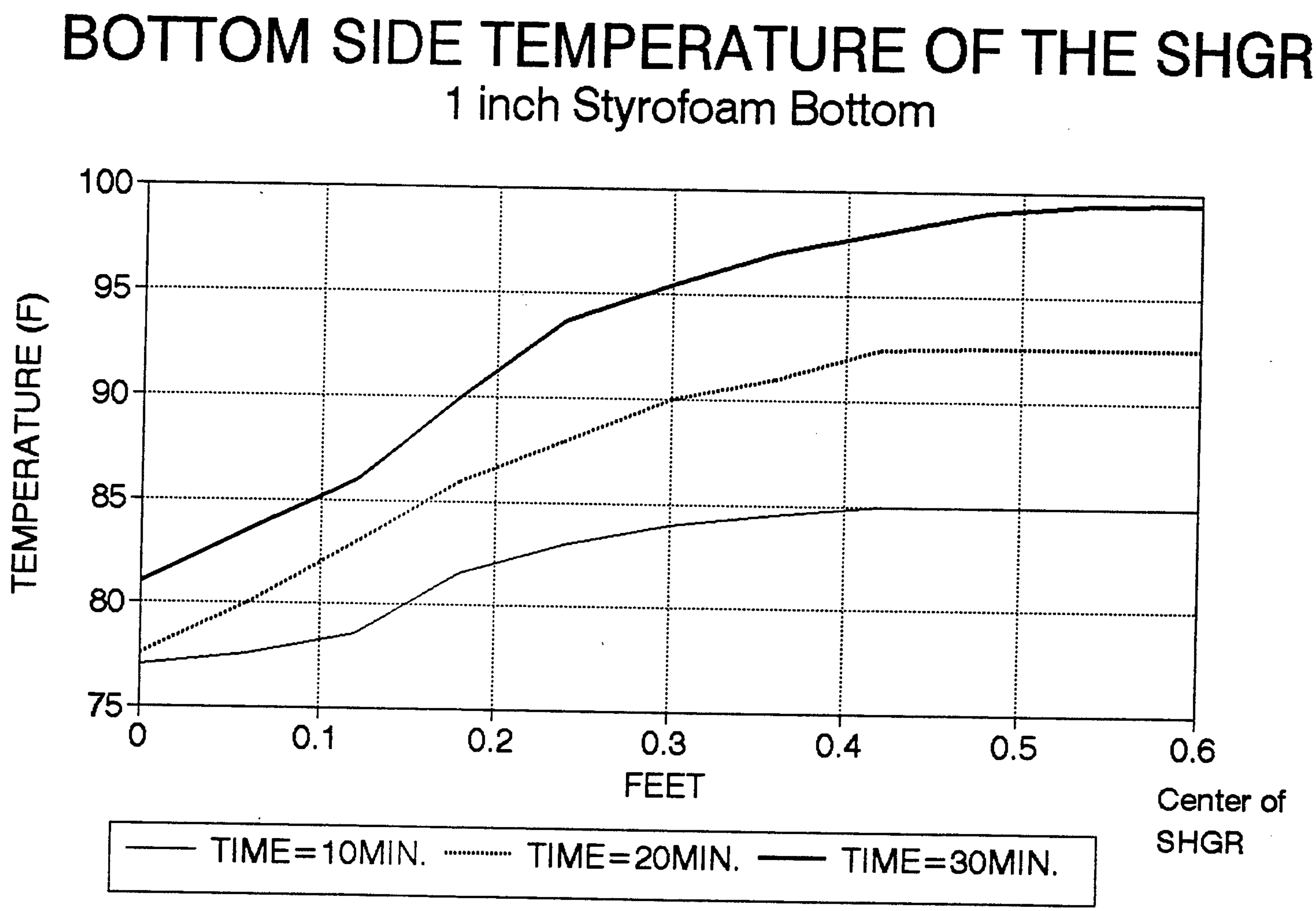
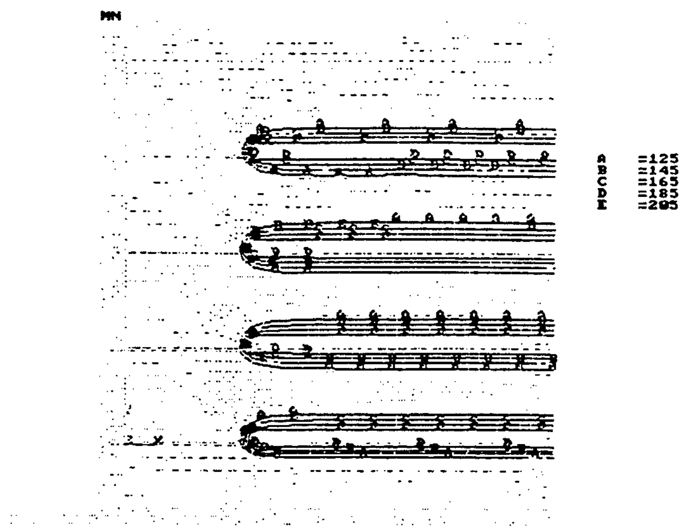
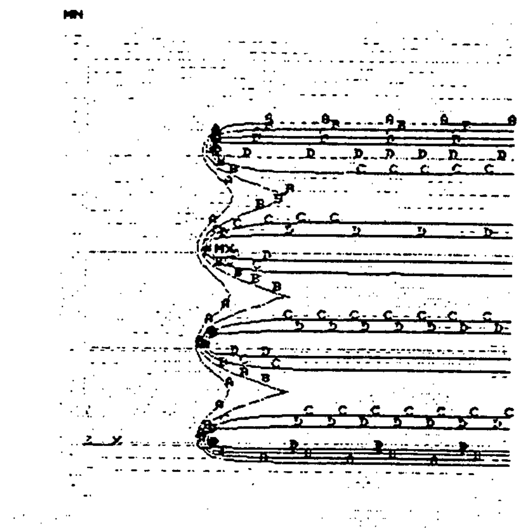


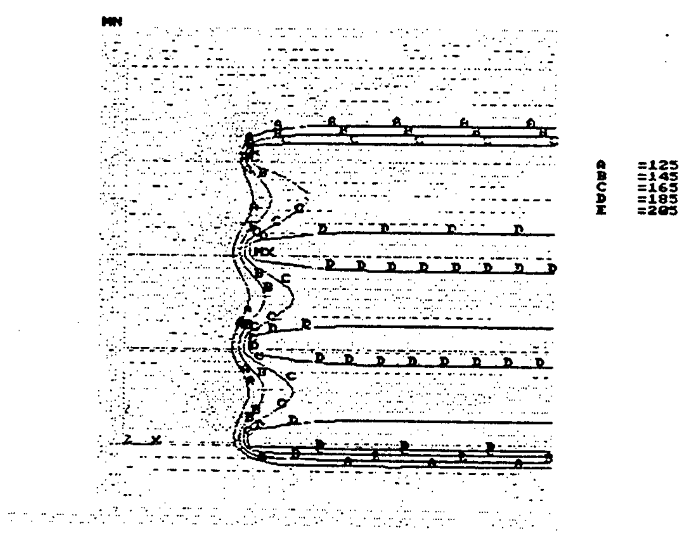

Figure 22: Temperature along the bottom side of the SHGR at 10, 20 and 30 minutes (1inch Styrofoam™ on the bottom of the SHGR).




a. SHGR at 10 minutes.

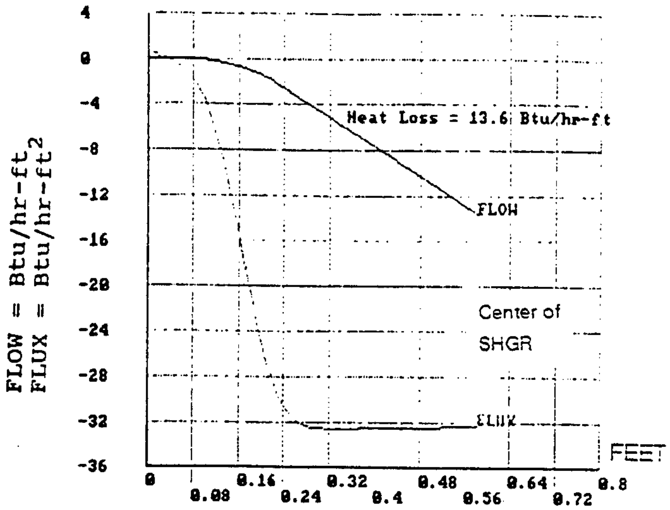



b. SHGR at 20 minutes.

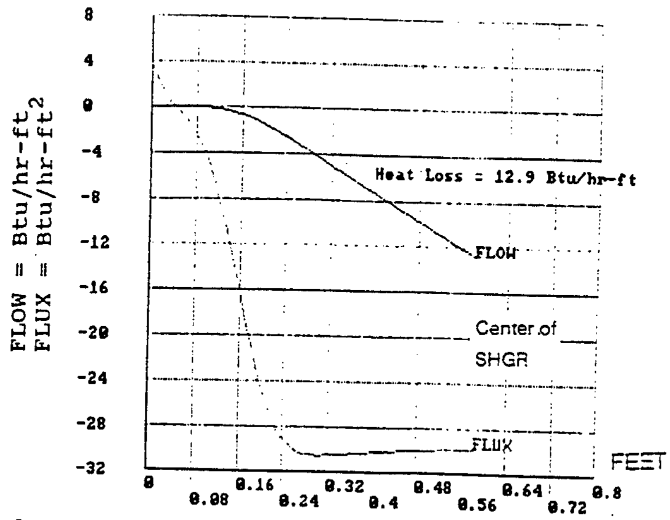



c. SHGR at 30 minutes.

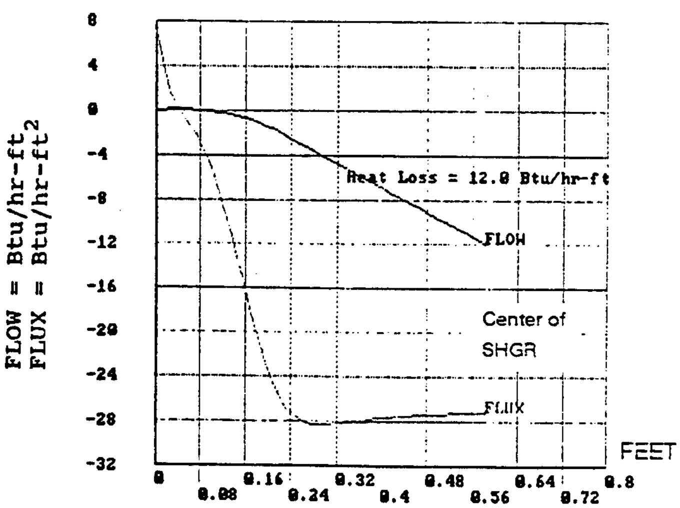
Figure 23: SHGR temperatures with corn and water in the third tray at 10, 20 and 30 minutes (1" Styrofoam on the Bottom of the SHGR).




a. Bottom side heat loss at 10 minutes (1" styrofoam).




b. Bottom side heat loss at 20 minutes (1" styrofoam).




c. Bottom side heat loss at 30 minutes (1" styrofoam).

Figure 24: Heat flow (q) and heat flux (q") for the Bottom Side of the SHGR at 10, 20 and 30 minutes (1" Styrofoam on the Bottom of the SHGR).

## FEM Model Results when $T_o$ = 40°F

In Figure 25 the results of the FEM model that predicted the top, left and bottom side temperatures are shown for the SHGR at 10, 20, and 30 minutes when the initial temperature of the SHGR was 40°F. Figure 26 shows the results of the general temperature of the SHGR at 10, 20 and 30 minutes.

## Analysis of SHGR when $T_o$ = 40°F

Heat flow (q) and heat flux (q") are shown for the top side of the SHGR in Figure 27 for 10, 20 and 30 minutes. In Figure 28 the predicted heat flow (q) and heat flux (q") are shown for the left side of the SHGR. Figure 29 shows the results of the FEM model that predicted the heat flow (q) and heat flux (q") for the bottom side of the SHGR at 10, 20 and 30 minutes. The total heat flow from the bottom side using Simpson's rule was 12.2 Btu/linear ft, from the top side 1.00 Btu/linear ft and 0.12 Btu/linear ft from the left side. The total heat loss for each side of the SHGR was as follows:

Top Side

1.00 Btu/ft * 2 (model symmetry) * 0.875 ft (depth of SHGR) = 1.8 Btu

Left Side (All Vertical Sides)

0.12 Btu/ft * ((0.875 ft (depth) * 2) + (1.125 * 2)) = 0.5 Btu

Bottom Side

12.2 Btu/ft * 2 (model symmetry) * 0.875 ft (depth) = 21.4 Btu

The Total predicted heat loss from SHGR was:

1.8 Btu + 0.5 Btu + 21.4 Btu = <u>23.7 Btu</u>

The bottom losses were 90% of the total heat lost from the container, and the total heat loss was 28.4% more than the SHGR at an ambient temperature of 76°F.

With a total heat input to the SHGR of 2080 Btu the total convective heat loss was still only 1.14% of the total heat input. The ANSYS code (File 18) for the standard SHGR model can be found in Appendix C. Appendix D contains the macros used in ANSYS for applying the loading conditions, and for calculating the heat loss from the top, left and bottom side.

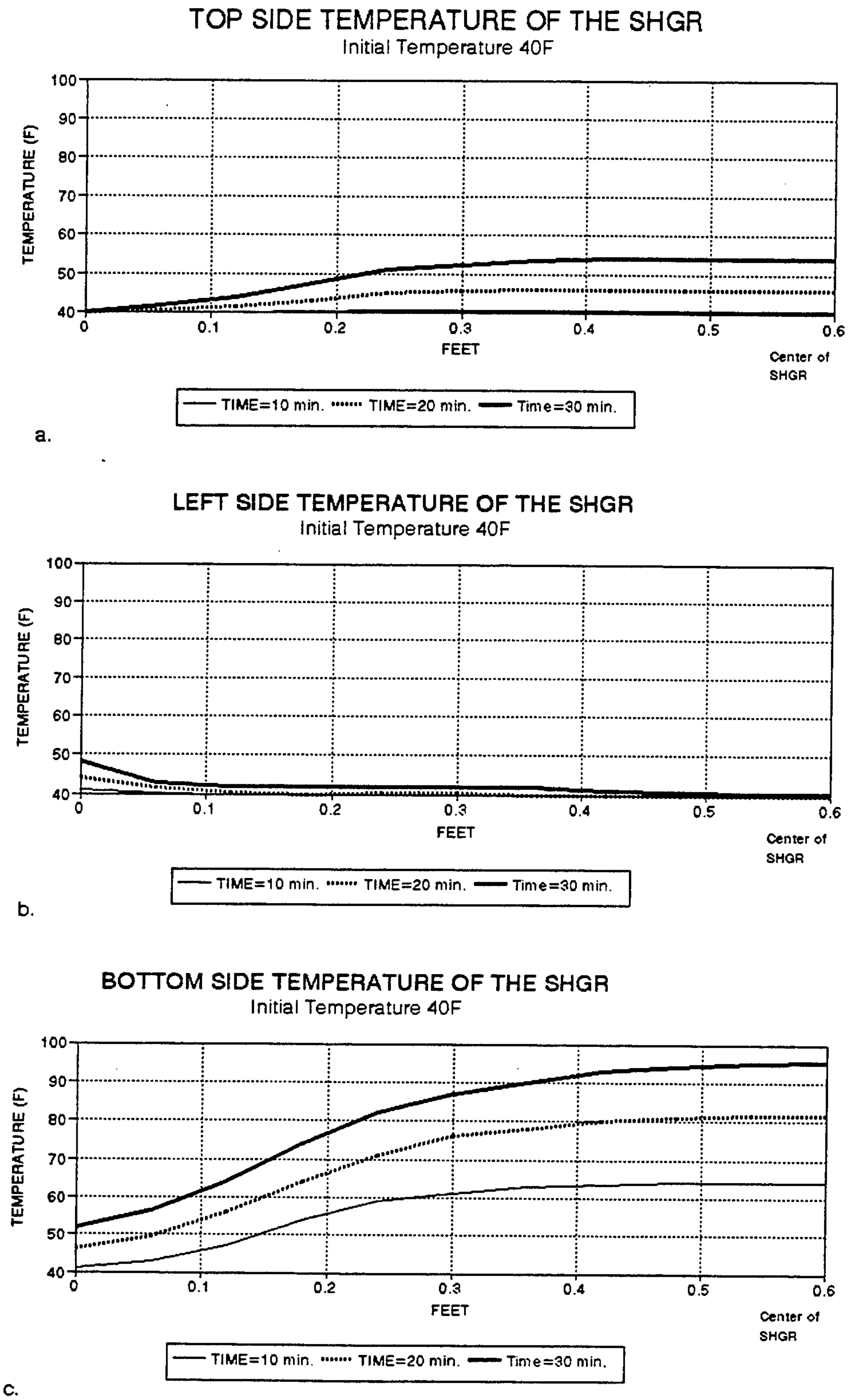
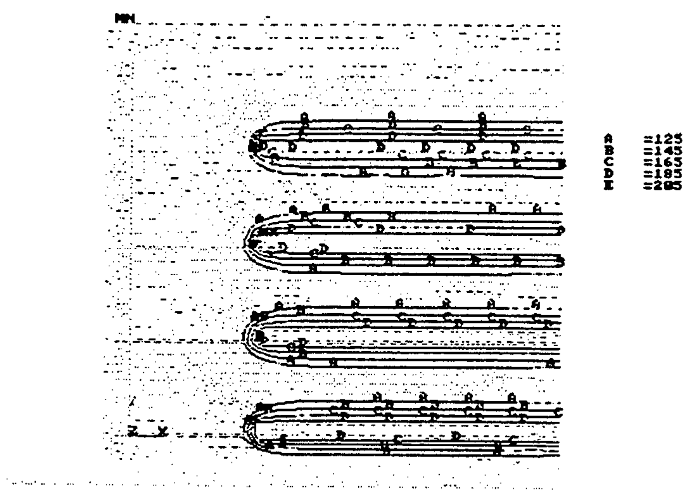
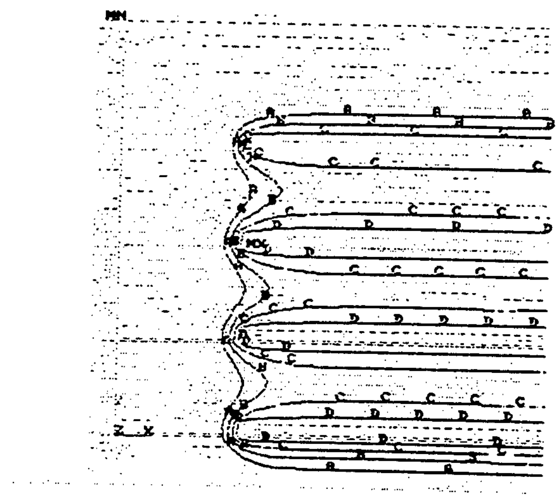


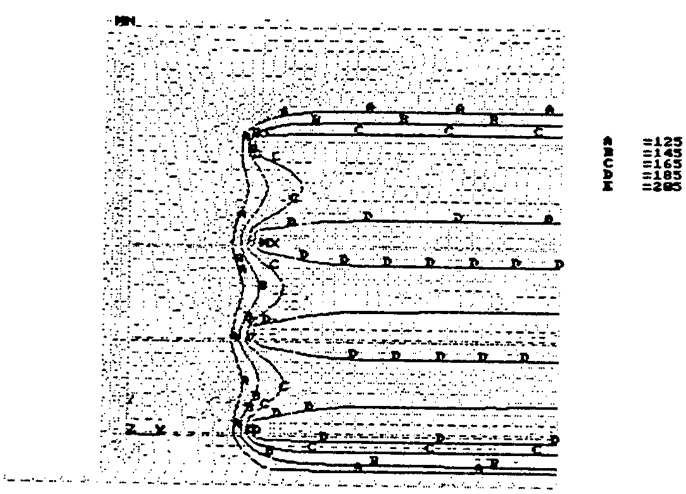

Figure 25: Temperature along the sides of the SHGR at 10, 20 and 30 minutes when the initial temperature of the SHGR is 40F (1/2 inch Styrofoam bottom).




a. SHGR at 10 minutes.

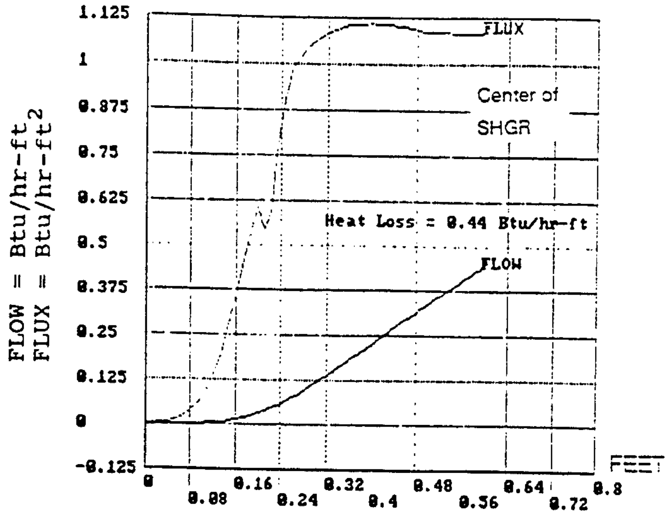


b. SHGR at 20 minutes.

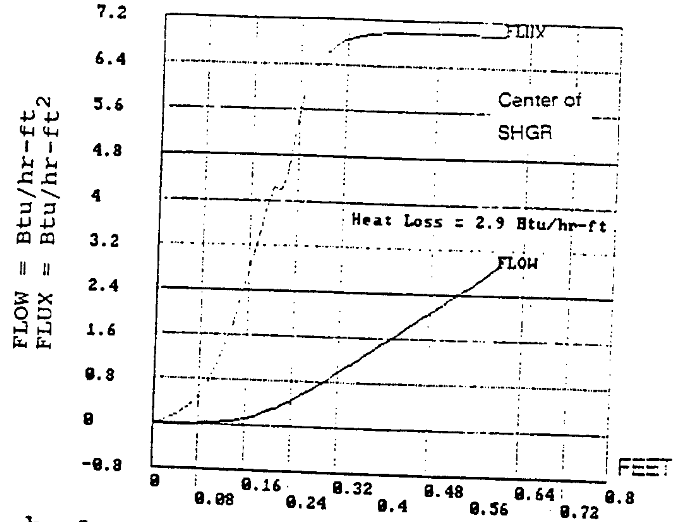



c. SHGR at 30 minutes.

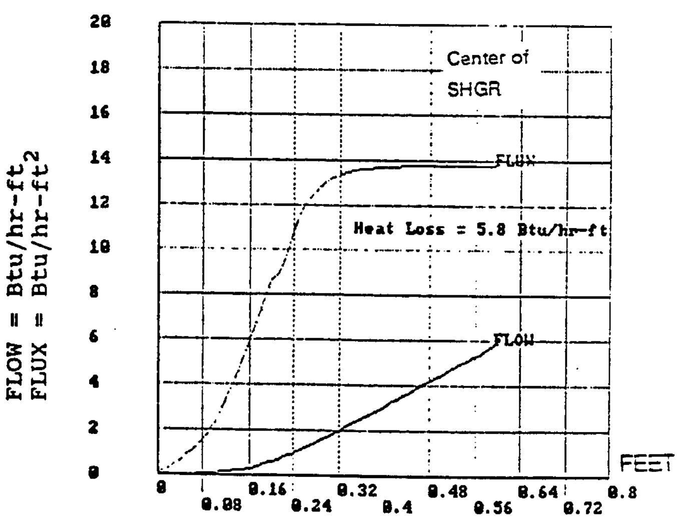
Figure 26: SHGR temperatures with corn and water in the third tray at 10, 20 and 30 minutes (Initial temperature 40°F).




a. Top side heat loss at 10 minutes (Ti=40F).

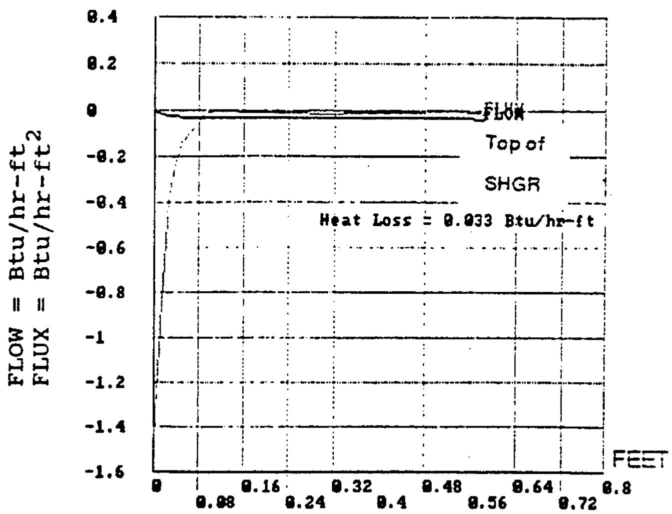



b. Top side heat loss at 20 minutes (Ti=40F).

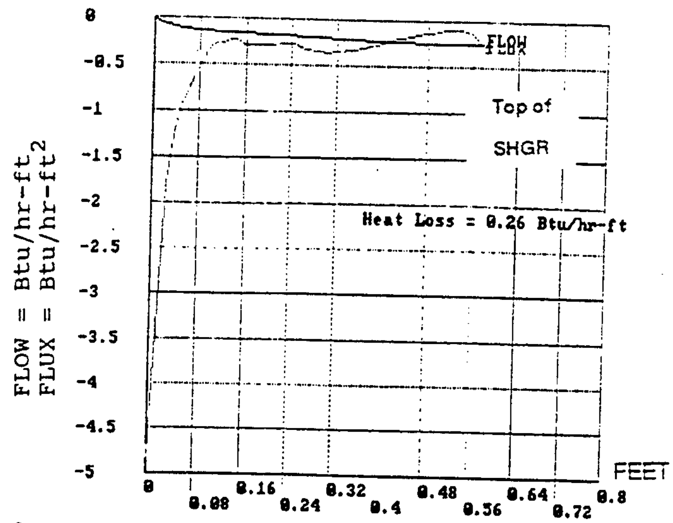



c. Top side heat loss at 30 minutes (Ti= 40F).

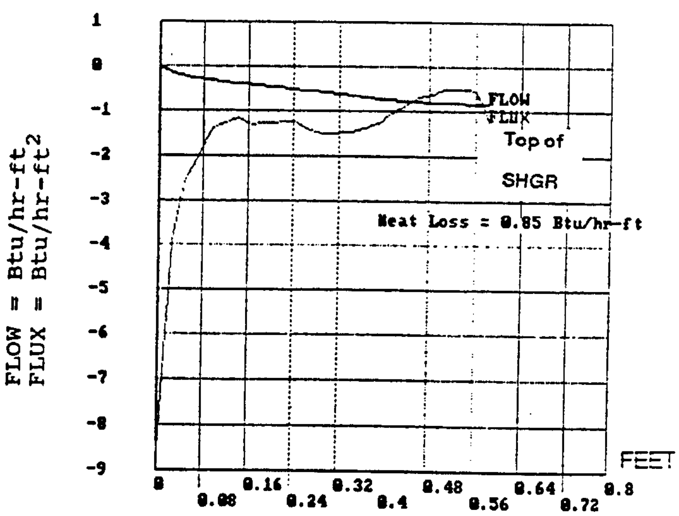
Figure 27: Heat flow (q) and heat flux (q") for the Top Side of the SHGR at 10, 20, and 30 minutes (Initial temperature 40°F).




a. Left side heat loss at 10 minutes (Ti=40F).

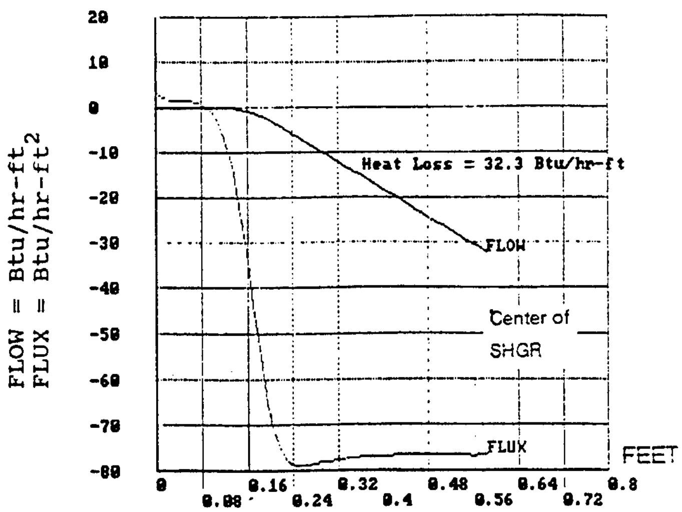



b. Left side heat loss at 20 minutes (Ti=40F).

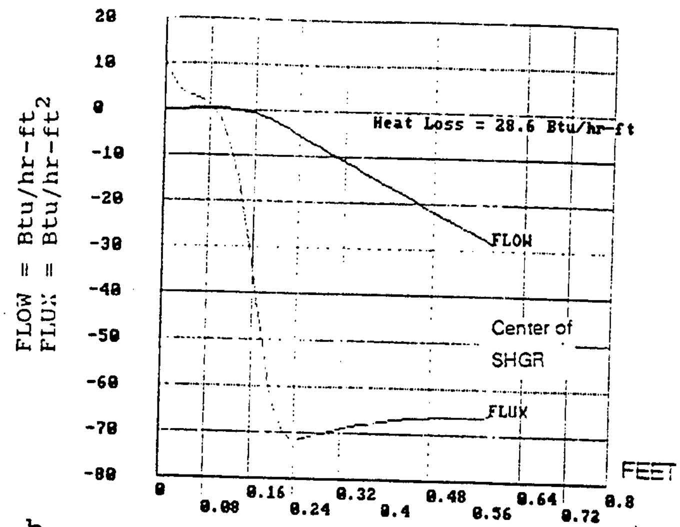



c. Left side heat loss at 30 minutes (Ti=40F).

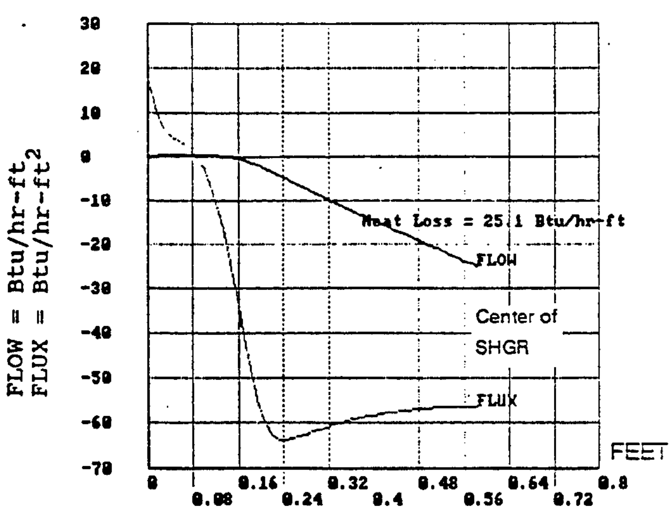
Figure 28: Heat flow (q) and heat flux (q") for the Left Side of the SHGR at 10, 20, and 30 minutes (Initial temperature 40°F).




a. Bottom side heat loss at 10 minutes (Ti=40F).




b. Bottom side heat loss at 20 minutes (Ti=40).




c. Bottom side heat loss at 30 minutes (Ti=40F).

Figure 29: Heat flow (q) and heat flux (q") for the Bottom Side of the SHGR at 10, 20, and 30 minutes (Initial temperature 40°F).

## RECOMMENDATIONS:

Although the 1-inch Styrofoam reduced the heat loss from the SHGR by 35.5%, the heat lost represents a very low percentage of the total heat supplied. Therefore the recommended solution is to use the 1/2-inch Styrofoam for the bottom of the SHGR (or standard configuration).

It is also recommended to put entrees that require less heat in the top tray. Placing entrees that require less warming in the top tray of the SHGR could cut the heating time from 30 minutes down to 15 to 20 minutes.

## CONCLUSION:

A FDM and FEM model were developed for the SHGR to simulate the heat transfer. The FDM model primarily predicted the temperature of food heated by the SHGR. The FEM model primarily predicted the heat loss from the SHGR.

The heat loss analysis revealed the bottom of the standard SHGR lost approximately 90% of the total heat lost by the SHGR in the first 30 minutes of heating. In an attempt to reduce the heat lost from the bottom an additional 1/2-inch of Styrofoam was added to the bottom. The added insulation reduced the heat loss from the bottom to 80% making the total heat loss 35.5% less than the standard configuration. Still the total heat loss from the standard SHGR with a 1/2-inch of Styrofoam was only 0.6% of the total heat input. Therefore a third FEM model considered the SHGR in a cold environment (40°F). The cold environment analysis indicated that the heat loss was approximately 28.4% greater than at the temperate condition where the initial temperature was 76°F. So the heat loss to the environment during the 40°F ambient condition was still only 0.94% of the total heat input. These results suggest the original container of the SHGR is an efficient design.

## FUTURE WORK:

Consideration could be given to model the hot air flows along the side of the SHGR using Computational Fluid Dynamics (CFD) to account for the top tray (#4) heating faster than the ANSYS model could predict. Work performed by Rochester Institute of Technology found similar convective flows occurring within the SHIMM. This type of modeling effort could easily be handled by the commercial code called FIDAP. Accordingly, a Tech-Base proposal was submitted to continue work on this work unit, but the proposal fell below the FY94 funding levels. This work unit is therefore terminated.

From the current analysis it appears that possibly both pieces of insulation from the top and bottom could be removed without a significant heat loss. The FEM model could be used to analyze the SHGR with no insulation or with an extra piece of fiberboard at the top and bottom, etc. The analysis should also include full size heaters.

Finally, the use of an infrared camera to measure experimentally the heat loss from the SHGR would be of considerable value. Actual heat lost from the SHGR could be determined and optimized FEM models thoroughly verified.

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2. Kanklikar S. G., Robertson W. R., Sundarraj V., Thermal Analysis and Development of Ration Packaging for Efficient Heating with Flameless Electrochemical Heaters, Mechanical Engineering Department, Rochester Institute of Technology, Rochester, New York, April 1992

3. Kim I., Thermal Design Optimization of Food Packages with Integral Heat Source, Food Engineering Directorate, U.S. Army Natick Research, Development and Engineering Center, October 1992

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APPENDIX A

Finite Difference Code

## PART 1 OF FINITE DIFFERENCE PROGRAM (GRP3.FOR)

```
c This program is the first of two programs for simulating the
c performance of the Self-Heating Group Ration (SHGR).  This program
c prepares the input file for the second Program called GROUP3.FOR
c by calculating the coefficients of the matrix formed by the implicit
c or backward difference method.  The limit of the number of nodes for
c these two programs is 50.


c VARIABLE DEFINITIONS OF INPUT VALUES
c ---------------------------------------

c   T(x,x) - matrix for the calculated coefficients from the implicit
c          or backward difference method to be solved by the
c          program GROUP3.FOR

c   B(x) - right hand side values for the T(x,x) matrix

c   File 'PV' - input values for the properties of the SHGR

c   N - number of nodes

c   NTIME - number of iterations to be performed for each time increment

c   TINC - time increment

c   TINT - initial temperature of the SHGR


c         THERMAL CONDUCTIVITIES

c   KCARD - cardboard

c   KSTYRO - styrofoam

c   KHEATER - flameless ration heater

c   KTUB - polypropylene tray

c   KBAG - tri-laminate pouch for food

c   KFOOD - ration in pouch


c         SPECIFIC HEATS - CCARD, CSTYRO, CHEATER ...

c         DENSITY - DCARD, DSTRYO, DHEATER ...

c         THICKNESS OR WIDTH - WCARD, WSTRYO, WHEATER ...

c   TBOT - ambient temperature at the bottom side of the SHGR
```

```
c     TTOP - ambient temperature at the top side of the SHGR
c     HTOP - convection coefficient on the top side of the SHGR

c     ATUB - bottom area of the polypropylene tray

c     AHEATER - area of heater in contact with pouch

c     AHEATOP - area of heater in contact with pouch on the top tray

c     DTIME - time increment for each iteration

c  ----------------------------------------------------------
c  ----------------------------------------------------------

C  Reading the input in from file 'PV':

      DIMENSION T(50,50), B(50)
      real kcard,kstyro,kheater,ktub,kbag,kfood
      OPEN(9,FILE='PV',FORM='FORMATTED')
      READ(9,15)N
       WRITE(*,15)N
   15 FORMAT(I4)
      READ(9,15)NTIME
       WRITE(*,20)NTIME
20    FORMAT(1X,'# OF ITERATIONS=',I4)
      READ(9,10)TINC
       WRITE(*,10)TINC
      READ(9,10)TINT
       WRITE(*,10)TINT

C  Reading in the thermal conductivity of the materials

      READ(9,10)KCARD
      write(*,200)kcard
  200      format(1x,'kcard=',f9.5)
      READ(9,10)KSTYRO
      write(*,210)kstyro
  210      format(1x,'kstyro=',f9.5)
      READ(9,10)KHEATER
      write(*,220)kheater
  220      format(1x,'kheater=',f9.5)
      READ(9,10)KTUB
      write(*,230)ktub
  230      format(1x,'ktub=',f9.5)   READ(9,10)KBAG
      write(*,240)kbag
  240      format(1x,'kbag=',f9.5)
      READ(9,10)KFOOD
      write(*,250)kfood
  250      format(1x,'kfood=',f9.5)

C   Reading in the specific heats of the materials
```

```
      READ(9,10)CCARD
      write(*,260)ccard
 260      format(1x,'ccard=',f9.5) READ(9,10)CSTYRO
      write(*,270)cstyro
 270  format(1x,'cstyro=',f9.5)
      READ(9,10)CHEATER
      write(*,280)cheater
 280  format(1x,'cheater=',f9.5)
      READ(9,10)CTUB
      write(*,290)ctub
 290  format(1x,'ctub=',f9.5)
      READ(9,10)CBAG
      write(*,300)cbag
 300  format(1x,'cbag=',f9.5)
      READ(9,10)CFOOD
      write(*,310)cfood
 310  format(1x,'cfood=',f9.5)

c  Reading in the density of the materials

      READ(9,10)DCARD
      write(*,320)dcard
 320  format(1x,'dcard=',f9.5)
      READ(9,10)DSTYRO
      write(*,330)dstyro
 330  format(1x,'dstyro=',f9.5)
      READ(9,10)DHEATER
      write(*,340)dheater
 340  format(1x,'dheater='f9.5)
      READ(9,10)DTUB
      write(*,350)dtub
 350  format(1x,'dtub=',f9.5)
      READ(9,10)DBAG
      write(*,360)dbag
 360  format(1x,'dbag=',f9.5)
      READ(9,10)DFOOD
      write(*,370)dfood
 370  format(1x,'dfood=',f9.5)

c  Reading in the thickness or width of the materials

      READ(9,10)WCARD
      write(*,380)wcard
 380  format(1x,'wcard=',f9.5)
      READ(9,10)WSTYRO
      write(*,390)wstyro
 390  format(1x,'wstro=',f9.5)

      READ(9,10)WHEATER
      write(*,400)wheater
```

```
 400 format(1x,'wheater=',f9.5)
     READ(9,10)WTUB
     write(*,410)wtub
 410 format(1x,'wtub=',f9.5)  READ(9,10)WBAG
     write(*,420)wbag
 420 format(1x,'wbag=',f9.5)
     READ(9,10)WFOOD
     write(*,430)wfood
 430 format(1x,'wfood=',f9.5)


c  Reading in the initial temperatures, convection coefficients,
c  areas and time increment.

     READ(9,10)TBOT
     write(*,440)tbot
 440 format(1x,'tbot=',f9.5)
     READ(9,10)TTOP
     write(*,450)ttop
450  format(1x,'ttop=',f9.5)
     READ(9,10)HTOP
     write(*,460)htop
460  format(1x,'htop=',f9.5)

     READ(9,10)ATUB
     write(*,470)atub
470  format(1x,'atub=',f9.5)
     READ(9,10)AHEATER
     write(*,480)aheater
 480 format(1x,'aheater=',f9.5)
     READ(9,10)AHEATOP
     write(*,485)aheatop
485  format(1x,'aheatop=',f9.5)     READ(9,10)DTIME
     write(*,490)dtime
490  format(1x,'dtime=',f9.5)
10   FORMAT(F9.5)

c  Input file 'PV' closed

     CLOSE(9)

c --------------------------------------------------------------------
c --------------------------------------------------------------------

c VARIABLE NAMES USED TO CALCULATE COEFFICIENTS

c    UB1 - overall conductivity between the bottom and the cardboard

c    U12 - overall conductivity between the cardboard and stryrofoam

c    U23 - overall conductivity between the styrofoam interior nodes

c    U3H - overall conductivity between the heater and styrofoam
```

```
c UH4 - overall conductivity between the heater and the pouch

c  UFOOD - overall conductivity between the food's interior nodes
c U9H - overall conductivity between the food in the top tray
c      and heater

c U1011 - overall conductivity between the food and styrofoam
c        on top tray

c U1112 - overall conductivity between the stryrofoam and
c        cardboard

c U12T - overall conductivity between the ambient and top
c       cardboard

c UH4T - overall conductivity between the food and pouch in
c       top tray

 UB1=(KCARD/(WCARD/4.))*ATUB
 U12=(1./((WCARD/1.)/KCARD+(WSTYRO/4.)/KSTYRO))*ATUB
 U23=(KSTYRO/(WSTYRO/2.))*ATUB
 U3H=(1./(WTUB/KTUB+(WSTYRO/4.)/KSTYRO))*AHEATER
 UH4=(1./((WFOOD/20.)/KFOOD+WBAG/KBAG))*AHEATER
 UFOOD=(KFOOD/(WFOOD/10.))*ATUB
 U9H=(1./((WFOOD/20.)/KFOOD+WTUB/KTUB))*AHEATER
 U1011=(1./((WFOOD/20.)/KFOOD+(WSTYRO/4.)/KSTYRO))*ATUB
 U1112=U12
 U12T=HTOP*ATUB
 UH4T=(1./((WFOOD/20.)/KFOOD+WBAG/KBAG))*AHEATOP

 write(*,510)ub1
 write(*,520)u12
 write(*,530)u23
 write(*,540)u3H
 write(*,550)uH4
 write(*,560)uFOOD
 write(*,565)u9h
 write(*,570)u1011
 write(*,580)u12t
510 FORMAT(1X,'UB1=',F9.5)
520 FORMAT(1X,'U12=',F9.5)
530 FORMAT(1X,'U23=',F9.5)
540 FORMAT(1X,'U3H=',F9.5)
550 FORMAT(1X,'U4H=',F9.5)
560 FORMAT(1X,'UFOOD=',F9.5)
565 FORMAT(1X,'U9H',F9.5)
570 FORMAT(1X,'U1011=',F9.5)
580 FORMAT(1X,'U12T=',F9.5)

c  XCARD, XSTYRO, XFOOD - constants from the right side of
c    equation (1) that are properties of the node
```

```
      XCARD=DTIME/(DCARD*WCARD*CCARD*ATUB)
      XSTYRO=DTIME/(DSTYRO*(WSTYRO/2.)*CSTYRO*ATUB)
      XFOOD=DTIME/(DFOOD*(WFOOD/10.)*CFOOD*ATUB)

      write(*,610)xcard
      write(*,620)xstyro
      write(*,630)xfood
 610  FORMAT(1X,'XCARD=',F9.5)
 620  FORMAT(1X,'XSTRYO=',F9.5)
 630  FORMAT(1X,'XFOOD=',F9.5)

c Initializing the coefficients array T(x,x) and right hand
c  side array B(x) to zero

      DO 40 I=1,N
      DO 30 J=1,N
      B(I)=0.
      T(I,J)=0.
 30   CONTINUE
 40   CONTINUE

c  The lines below calculate the coefficients for the T(x,x) c  and B(x)
arrays.

      T(1,1)=1.+XCARD*(UB1+U12)
      T(1,2)=(-XCARD*U12)
      B(1)=XCARD*TBOT*UB1

      T(2,1)=-XSTYRO*U12
      T(2,2)=1.+XSTYRO*(U12+U23)
      T(2,3)=(-XSTYRO)*U23

      T(3,3)=1+XSTYRO*(U23+U3H)
      T(3,2)=(-XSTYRO)*U23
      B(3)=XSTYRO*U3H

      T(4,5)=-XFOOD*UFOOD
      T(4,4)=1.+ XFOOD*(UFOOD+UH4)
      B(4)=XFOOD*UH4

      T(5,5)=1.+XFOOD*(UFOOD+UFOOD)
      T(5,6)=-XFOOD*UFOOD
      T(5,4)=-XFOOD*UFOOD

      DO 680 I=6,12
      T(I,I-1)=T(5,4)
      T(I,I)=T(5,5)
      T(I,I+1)=T(5,6)
 680  CONTINUE

      T(13,12)=-XFOOD*UFOOD
      T(13,13)=1.+XFOOD*(UFOOD+U9H)
```

```
      B(13)=XFOOD*U9H


      DO 650 I = 15,22
      T(I,I-1)=T(5,4)
      T(I,I)=T(5,5)
      T(I,I+1)=T(5,6)
650         CONTINUE
      DO 660 I = 25,32
      T(I,I-1)=T(5,4)
      T(I,I)=T(5,5)
      T(I,I+1)=T(5,6)
660         CONTINUE
      DO 670 I = 35,42
      T(I,I-1)=T(5,4)
      T(I,I)=T(5,5)
      T(I,I+1)=T(5,6)
670         CONTINUE
      T(14,14)=T(4,4)
      T(14,15)=T(4,5)
      B(14)=B(4)
      T(24,24)=T(4,4)
      T(24,25)=T(4,5)
      B(24)=B(4)
      T(34,34)=1.+XFOOD*(UFOOD+UH4T)
      T(34,35)=T(4,5)
      B(34)=XFOOD*UH4T

      T(23,22)=T(13,12)
      T(23,23)=T(13,13)
      B(23)=B(13)
      T(33,32)=T(13,12)
      T(33,33)=T(13,13)
      B(33)=B(13)

      T(43,42)=-XFOOD*UFOOD
      T(43,43)=1.+XFOOD*(UFOOD+U1011)
      T(43,44)=-XFOOD*U1011

      T(44,43)=-XSTYRO*U1011
      T(44,44)=1.+XSTYRO*(U1011+U23)
      T(44,45)=-XSTYRO*U23

      T(45,44)=-XSTYRO*U23
      T(45,45)=1.+XSTYRO*(U23+U12)
      T(45,46)=-XSTYRO*U12

      T(46,45)=-XCARD*U1112
      T(46,46)=1.+XCARD*(U1112+U12T)
      B(46)=U12T*XCARD*TTOP
```

```
c  The lines below write the T(x,x) and B(x) arrays
c  and other constants to the output file 'GC' for the
c  GROUP3.FOR program to solve.

      VV=.01
      OPEN(9,FILE='GC',FORM='FORMATTED')
      WRITE(9,140)N,NTIME,VV
140   FORMAT(2I3,F5.2)
      WRITE(9,150)TINC
      WRITE(9,150)TINT
150   FORMAT(F5.2)

      DO 100 I = 1,N
      DO 110 J = 1,N
      WRITE(9,120)T(I,J)
 110  CONTINUE
 100  CONTINUE

      DO 130 I = 1,N
      WRITE(9,120)B(I)
 130  CONTINUE
 120  FORMAT(F12.5)
      CLOSE(9)
      STOP
      END
```

## PART II OF FINITE DIFFERENCE PROGRAM (GROUP3.FOR)

```
c   This is the second of two programs for simulating the
c   performance of the Self-Heating Group Ration (SHGR).  This
c   program solves the matrix coefficients prepared by the
c   first program GRP3.FOR by matrix inversion.

c    A(x,x) - calculated coefficient matrix from the implicit
c             or backward difference method to be solved for
c             the SHGR

c    B(x) - new right hand side values

c    C(x,x) - inverted matrix of A(x,x) produced from MATINV
c             subroutine

c    T(x) - array is used in solution for the temperatures

c    TEMP(x,1) - temperature values for the heaters in the
c                lower three trays in the SHGR

c    TEMP(x,2) - temperature values for the heaters in the
c                top tray of the SHGR

c    BZ(x) - original right hand side values

c    TE(x,x) - array used to hold all the temperatures
c              solutions

c         N - number of nodes

c         NTIME - number of iteration to be performed for each
c                 time increment

c         DELX - originally used as distance between nodes, but
c                not used when GRP3.FOR program is used

c         DELT - time increment for each iteration

c         TO - initial temperature of the SHGR


      DIMENSION A(50,50),B(50),C(50,50),T(50),TEMP(60,2),BZ(50),
     3 TE(60,35)
      open(9,file='GC',FORM='FORMATTED')
      READ (9,11) N,NTIME,DELX
      READ (9,12) DELT
      READ (9,12) TO
      write (*,23) N,NTIME,DELX,DELT,TO

c The lines below initialized all the arrays to zero.

      do 5 j=1,50
```

```
      do 4 i=1,50
      a(i,j)=0.
      b(i)=0.
      BZ(I)=0.
      c(i,j)=0.
      t(i)=0.
 4    continue
 5    continue

c  The lines below read in the arrays from file 'GC'.

      DO 18 I=1,N
      DO 22 J=1,N
      READ (9,12) A(I,J)
 22   CONTINUE
 18   CONTINUE

 400 CONTINUE

      DO 410 I=1,N
     READ(9,12) BZ(I)
 410      CONTINUE

 23 FORMAT (2I3,3F9.4)
 11   format (2I3,F9.4)
 12   format (F12.5)

c  File 'GC' is closed.
     CLOSE(9)

c  The file with the temperatures for the heaters is opened and
c  read into array TEMP(x,1).  These temperatures are the
c  average for the bottom three trays.

      open(9,file='TC',FORM='FORMATTED')

     DO 7 K=1,NTIME
     READ (9,12) TEMP(K,1)
7    CONTINUE
        CLOSE(9)

c  The file with the temperatures for the heaters in the
c  top tray is open and read into array TEMP(x,2).

        open(9,file='TCTOP',FORM='FORMATTED')

     DO 8 K=1,NTIME
     READ (9,12) TEMP(K,2)
8    CONTINUE

c  The input data has now all been read into the program and
c  the lines below start the output and solution.

     WRITE (*,10)DELT,TO
```

```
      close(9)

  10   FORMAT(1H,'***TRANSIENT TEMPERATURE DISTRIBUTION IN DEGREES',/,
      1'F DETERMINED BY AN IMPLICIT NUMERICAL TECHNIQUE***',/,
      2'TIME INTERVAL=',F8.3,
      3'SECONDS',/,'ORIGINAL TEMPERATURE=',F8.2,'DEGREES C')

c  Inversion of matrix A(x,x) is started by calling subroutine
c  MATINV and the inverse of matrix A(x,x) is returned in
c  matrix C(x,x) whose size is N x N.

       CALL MATINV(A,N,C)
       DO 15 I=1,N
15     T(I)=TO

c  The line below opens the output file for this program.
c  Note the extension 'wq1' is added for convenience
c  for importing this file into QUATTRO PRO as an
c  ASCII file.

             open(9,file='out.wq1',FORM='FORMATTED')

             DO 80 JJ=1,NTIME
      DO 75 II=2,33
       B(II)=T(II)+BZ(II)*TEMP(JJ,1)
75    CONTINUE
       DO 76 II=34,45
76     B(II)=T(II)+BZ(II)*TEMP(JJ,2)
       B(N)=BZ(N)+T(N)
       B(1)=bz(1)+T(1)

       DO 50 I=1,N
       SUM=0.0
       DO 40 J=1,N
40     SUM=SUM+C(I,J)*B(J)
      TE(I,JJ)=SUM
50      T(I)=SUM
       AJ=JJ
       TIME=JJ*DELT
       WRITE(9,70)TIME,(I,T(I),I=1,N)
70     FORMAT(/,'TIME=',F8.2,3x,'MINS',/,4('T(',
      1 I2,')=',F8.2,2X))

       avg1= 0.
       avg2= 0.
       avg3= 0.
       avg4= 0.

c The lines below calculate the average food temperature for
c each tray.

      DO 777 KI=1,10
```

```
      AVG1=AVG1+T(KI+33)
      AVG2=AVG2+T(KI+23)
      AVG3=AVG3+T(KI+13)
      AVG4=AVG4+T(KI+3)
 777  CONTINUE
      AVG1=AVG1/10.
      AVG2=AVG2/10.
      AVG3=AVG3/10.
      AVG4=AVG4/10.
        TE(N+1,JJ)=AVG1
      TE(N+2,JJ)=AVG2
      TE(N+3,JJ)=AVG3
      TE(N+4,JJ)=AVG4

      write(9,100)avg1
      write(9,110)avg2
      write(9,120)avg3
      write(9,130)avg4

100   Format(/,'Avg top=',F6.2)
110   Format(/,'Avg #2 =',F6.2)
120   Format(/,'Avg #3 =',F6.2)
130   Format(/,'Avg #4 =',F6.2)


80    CONTINUE
        DO 220 J=1,N+6,6

c  The lines below write a second solution to the output file
c  that can be parsed and plotted in QUATTRO PRO.

      WRITE(9,230)(I,I=J,J+5)
        WRITE(9,210)((TE(I,K),I=J,J+5),K=1,NTIME)

210   FORMAT(1X,6F10.1)
230   FORMAT(/,6(2X,'TN ',I2,3X))
220    CONTINUE
       STOP
       END


C INVERSION SUBROUTINE FOR FINITE DIFFERENCE PROGRAM IS LIMITED
C FOR A 50 X 50 MATRIX.

       SUBROUTINE MATINV (AA,N,AINV)
       DIMENSION AA(50,50),AINV(50,50),A(50,100),ID(50)
       NN=N+1
       N2=2*N
       DO 100 I=1,N
       ID(I)=I
       DO 100 J=1,N
100    A(I,J)=AA(I,J)
       DO 200 I=1,N
```

```
      DO 200 J=NN,N2
200   A(I,J)=0.
      DO 300 I=1,N
300   A(I,N+I)=1.
      K=1
1     CALL EXCH(A,N,N,N2,K,ID)
2     IF (A(K,K))3,999,3
3     KK=K+1
      DO 4 J=KK,N2
      A(K,J)=A(K,J)/A(K,K)
      DO 4 I=1,N
      IF(K-I)41,4,41
41    W=A(I,K)*A(K,J)
      A(I,J)=A(I,J)-W
      IF(ABS(A(I,J))-0.0001*ABS(W))42,4,4
42    A(I,J)=0.0
4     CONTINUE
      K=KK
      IF(K-N)1,2,5
5     DO 10 I=1,N
      DO 10 J=1,N
      IF(ID(J)-I)10,8,10
8     DO 101 K=1,N
101   AINV(I,K)=A(J,N+K)
10    CONTINUE
      RETURN
999   PRINT 1000
      RETURN
1000  FORMAT(19H MATRIX IS SINGULAR)
      END


      SUBROUTINE EXCH(A,N,NA,NB,K,ID)
      DIMENSION A(50,100),ID(50)
      NROW=K
      NCOL=K
      B=ABS(A(K,K))
      DO 2 I=K,N
      DO 2 J=K,NA
      IF (ABS(A(I,J))-B)2,2,21
21    NROW=I
      NCOL=J
      B=ABS(A(I,J))
2     CONTINUE
      IF (NROW-K)3,3,31
31    DO 32 J=K,NB
      C=A(NROW,J)
      A(NROW,J)=A(K,J)
32    A(K,J)=C
3     CONTINUE
      IF (NCOL-K)4,4,41
41    DO 42 I =1,N
```

```
      C=A(I,NCOL)
      A(I,NCOL)=A(I,K)
42    A(I,K)=C
      I=ID(NCOL)
      ID(NCOL)=ID(K)
      ID(K)=I
4     CONTINUE
      RETURN
      END
```

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## APPENDIX B

Sample I/O Files for the Finite Difference Code

## SAMPLE OF FILE PV

PV is the input file for the GRP3.FOR program. The PV file primarily contains the material properties for the SHGR.

| | |
|---|---|
| 46 | Number of nodes |
| 30 | Time length of analysis |
| 1. | Time increment in minutes |
| 75. | Initial temperature of the SHGR |
| 0.202 | Thermal conductivity of the fiberboard |
| 0.025 | Thermal conductivity of the styrofoam |
| 6.0 | Thermal conductivity of the heater |
| 0.0812 | Thermal conductivity of the tray |
| .173 | Thermal conductivity of the tri-laminate pouch |
| .0996 | Thermal conductivity of the food |
| 0.48 | Specific heat of the fiberboard |
| 0.48 | Specific heat of the styrofoam |
| 0.1 | Specific heat of the heater |
| 0.46 | Specific heat of the tray |
| 0.48 | Specific heat of the tri-laminate pouch |
| .366 | Specific heat of the food |
| 21.3 | Density of the fiberboard |
| 2.0 | Denisty of the styrofoam |
| 37.45 | Density of the heater |
| 65.55 | Density of the tray |
| 137.3 | Density of the tri-laminate pouch |
| 47.1 | Density of the food |
| .0104 | Thichness of the fiberboard |
| .04167 | Thickness of the styrofoam |
| .0259 | Thickness of the heater |
| .0031 | Thickness of the tray |
| .0003 | Thickness of the tri-laminate pouch |
| .1557 | Thickness of the food |
| 78.5 | Initial temperature of the bottom of the SHGR |
| 84.5 | Initial temperature of the top of the SHGR |
| .88 | Convection coefficient of the SHGR box |
| .90 | Area of the tray |
| .556 | Area of the heater |
| .556 | Area of the top heater |
| .01667 | Time increment in hours |

# SAMPLE OF FILE TCTOP

TCTOP is the file for the temperatures for the top tray's chemical heater for the FDM model. The file is an input file for the program GROUP3.FOR.

```
199.9
198.
198.4
196.3
196.8
197.9
195.4
192.5
188.5
186.5
183.8
182.9
181.8
181.1
181.1
180.9
181.
180.6
180.3
180.
179.6
179.4
179.3
179.1
178.9
178.8
178.6
178.5
178.4
178.3
178.2
```

## SAMPLE OF FILE TC

TC is the file for the temperatures for the bottom three tray's chemical heaters for the FDM model. The file is an input file for the program GROUP3.FOR.

```
74.3
195.6
198.6
199.6
196.8
195.3
197.
198.6
199.4
198.7
201.
201.
200.5
199.7
199.
198.7
198.3
198.1
199.2
200.1
200.5
200.1
199.7
199.1
198.6
198.1
197.6
197.1
196.7
196.4
196.2
```

## SAMPLE OF FILE OUT.WQ1

OUT.WQ1 is the solution or output file from GROUP3.FOR. The file is written in standard ASCII format.

```
TIME=     1.00   MINS
T( 1)=   78.19   T( 2)=    76.57   T( 3)=    75.25   T( 4)=    74.81
T( 5)=   74.96   T( 6)=    74.99   T( 7)=    75.00   T( 8)=    75.00
T( 9)=   75.00   T(10)=    75.00   T(11)=    74.99   T(12)=    74.97
T(13)=   74.86   T(14)=    74.81   T(15)=    74.96   T(16)=    74.99
T(17)=   75.00   T(18)=    75.00   T(19)=    75.00   T(20)=    75.00
T(21)=   74.99   T(22)=    74.97   T(23)=    74.86   T(24)=    74.81
T(25)=   74.96   T(26)=    74.99   T(27)=    75.00   T(28)=    75.00
T(29)=   75.00   T(30)=    75.00   T(31)=    74.99   T(32)=    74.97
T(33)=   74.86   T(34)=    74.81   T(35)=    74.96   T(36)=    74.99
T(37)=   75.00   T(38)=    75.00   T(39)=    75.00   T(40)=    75.00
T(41)=   75.00   T(42)=    75.00   T(43)=    75.01   T(44)=    75.14
T(45)=   75.51   T(46)=    76.01
Avg top= 74.98

Avg #2 = 74.96

Avg #3 = 74.96

Avg #4 = 74.96

TIME=     2.00   MINS
T( 1)=   78.76   T( 2)=    90.01   T( 3)=   123.46   T( 4)=   107.34
T( 5)=   82.52   T( 6)=    76.75   T( 7)=    75.41   T( 8)=    75.11
T( 9)=   75.09   T(10)=    75.31   T(11)=    76.31   T(12)=    80.64
T(13)=   99.25   T(14)=   107.34   T(15)=    82.52   T(16)=    76.75
T(17)=   75.41   T(18)=    75.11   T(19)=    75.09   T(20)=    75.31
T(21)=   76.31   T(22)=    80.64   T(23)=    99.25   T(24)=   107.34
T(25)=   82.52   T(26)=    76.75   T(27)=    75.41   T(28)=    75.11
T(29)=   75.09   T(30)=    75.31   T(31)=    76.31   T(32)=    80.64
T(33)=   99.25   T(34)=   107.34   T(35)=    82.52   T(36)=    76.75
T(37)=   75.41   T(38)=    75.10   T(39)=    75.02   T(40)=    75.01
T(41)=   75.01   T(42)=    75.01   T(43)=    75.04   T(44)=    75.35
T(45)=   76.09   T(46)=    76.82
Avg top= 79.22

Avg #2 = 82.37

Avg #3 = 82.37

Avg #4 = 82.37

TIME=     3.00   MINS
T( 1)=   79.02   T( 2)=    98.78   T( 3)=   142.74   T( 4)=   127.42
T( 5)=   91.91   T( 6)=    80.04   T( 7)=    76.45   T( 8)=    75.47
T( 9)=   75.41   T(10)=    76.12   T(11)=    78.86   T(12)=    87.99
T(13)=  115.63   T(14)=   127.42   T(15)=    91.91   T(16)=    80.04
T(17)=   76.45   T(18)=    75.47   T(19)=    75.41   T(20)=    76.12
```

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T(21)= | 78.86 | T(22)= | 87.99 | T(23)= | 115.63 | T(24)= | 127.42 |
| T(25)= | 91.91 | T(26)= | 80.04 | T(27)= | 76.45 | T(28)= | 75.47 |
| T(29)= | 75.41 | T(30)= | 76.12 | T(31)= | 78.86 | T(32)= | 87.99 |
| T(33)= | 115.63 | T(34)= | 127.42 | T(35)= | 91.91 | T(36)= | 80.04 |
| T(37)= | 76.43 | T(38)= | 75.39 | T(39)= | 75.11 | T(40)= | 75.03 |
| T(41)= | 75.02 | T(42)= | 75.03 | T(43)= | 75.08 | T(44)= | 75.57 |
| T(45)= | 76.61 | T(46)= | 77.49 | | | | |

Avg top= 82.65

Avg #2 = 88.53

Avg #3 = 88.53

Avg #4 = 88.53

TIME= 4.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.15 | T( 2)= | 103.27 | T( 3)= | 150.68 | T( 4)= | 140.27 |
| T( 5)= | 100.92 | T( 6)= | 84.24 | T( 7)= | 78.12 | T( 8)= | 76.18 |
| T( 9)= | 76.03 | T(10)= | 77.44 | T(11)= | 82.19 | T(12)= | 95.34 |
| T(13)= | 127.00 | T(14)= | 140.27 | T(15)= | 100.92 | T(16)= | 84.24 |
| T(17)= | 78.12 | T(18)= | 76.18 | T(19)= | 76.03 | T(20)= | 77.44 |
| T(21)= | 82.19 | T(22)= | 95.34 | T(23)= | 127.00 | T(24)= | 140.27 |
| T(25)= | 100.92 | T(26)= | 84.24 | T(27)= | 78.12 | T(28)= | 76.18 |
| T(29)= | 76.03 | T(30)= | 77.44 | T(31)= | 82.19 | T(32)= | 95.34 |
| T(33)= | 127.00 | T(34)= | 140.27 | T(35)= | 100.92 | T(36)= | 84.22 |
| T(37)= | 78.05 | T(38)= | 75.96 | T(39)= | 75.29 | T(40)= | 75.09 |
| T(41)= | 75.04 | T(42)= | 75.06 | T(43)= | 75.13 | T(44)= | 75.78 |
| T(45)= | 77.07 | T(46)= | 78.05 | | | | |

Avg top= 85.50

Avg #2 = 93.77

Avg #3 = 93.77

Avg #4 = 93.77

TIME= 5.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.21 | T( 2)= | 105.03 | T( 3)= | 152.77 | T( 4)= | 148.04 |
| T( 5)= | 108.66 | T( 6)= | 88.77 | T( 7)= | 80.29 | T( 8)= | 77.28 |
| T( 9)= | 77.01 | T(10)= | 79.22 | T(11)= | 85.91 | T(12)= | 101.94 |
| T(13)= | 134.56 | T(14)= | 148.04 | T(15)= | 108.66 | T(16)= | 88.77 |
| T(17)= | 80.29 | T(18)= | 77.28 | T(19)= | 77.01 | T(20)= | 79.22 |
| T(21)= | 85.91 | T(22)= | 101.94 | T(23)= | 134.56 | T(24)= | 148.04 |
| T(25)= | 108.66 | T(26)= | 88.77 | T(27)= | 80.29 | T(28)= | 77.28 |
| T(29)= | 77.01 | T(30)= | 79.22 | T(31)= | 85.91 | T(32)= | 101.94 |
| T(33)= | 134.56 | T(34)= | 148.04 | T(35)= | 108.65 | T(36)= | 88.73 |
| T(37)= | 80.14 | T(38)= | 76.81 | T(39)= | 75.61 | T(40)= | 75.21 |
| T(41)= | 75.09 | T(42)= | 75.09 | T(43)= | 75.19 | T(44)= | 75.97 |
| T(45)= | 77.46 | T(46)= | 78.52 | | | | |

Avg top= 87.86

Avg #2 = 98.17

```
Avg #3 = 98.17

Avg #4 = 98.17

TIME=     6.00   MINS
T( 1)=   79.22   T( 2)=   105.59   T( 3)=   153.08   T( 4)=   153.16
T( 5)=  115.11   T( 6)=    93.29   T( 7)=    82.83   T( 8)=    78.74
T( 9)=   78.36   T(10)=    81.35   T(11)=    89.71   T(12)=   107.65
T(13)=  139.97   T(14)=   153.16   T(15)=   115.11   T(16)=    93.29
T(17)=   82.83   T(18)=    78.74   T(19)=    78.36   T(20)=    81.35
T(21)=   89.71   T(22)=   107.65   T(23)=   139.97   T(24)=   153.16
T(25)=  115.11   T(26)=    93.29   T(27)=    82.83   T(28)=    78.74
T(29)=   78.36   T(30)=    81.35   T(31)=    89.71   T(32)=   107.65
T(33)=  139.97   T(34)=   153.15   T(35)=   115.08   T(36)=    93.19
T(37)=   82.54   T(38)=    77.91   T(39)=    76.07   T(40)=    75.39
T(41)=   75.17   T(42)=    75.15   T(43)=    75.26   T(44)=    76.14
T(45)=   77.80   T(46)=    78.92
Avg top= 89.89

Avg #2 =102.02

Avg #3 =102.02

Avg #4 =102.02

TIME=     7.00   MINS
T( 1)=   79.23   T( 2)=   105.96   T( 3)=   153.91   T( 4)=   157.49
T( 5)=  120.63   T( 6)=    97.64   T( 7)=    85.60   T( 8)=    80.55
T( 9)=   80.04   T(10)=    83.75   T(11)=    93.48   T(12)=   112.69
T(13)=  144.59   T(14)=   157.49   T(15)=   120.63   T(16)=    97.64
T(17)=   85.60   T(18)=    80.55   T(19)=    80.04   T(20)=    83.75
T(21)=   93.48   T(22)=   112.69   T(23)=   144.59   T(24)=   157.49
T(25)=  120.63   T(26)=    97.64   T(27)=    85.60   T(28)=    80.55
T(29)=   80.04   T(30)=    83.75   T(31)=    93.48   T(32)=   112.69
T(33)=  144.59   T(34)=   157.47   T(35)=
 120.57   T(36)=    97.46
T(37)=   85.11   T(38)=    79.24   T(39)=    76.68   T(40)=    75.65
T(41)=   75.29   T(42)=    75.22   T(43)=    75.33   T(44)=    76.30
T(45)=   78.09   T(46)=    79.25
Avg top= 91.80

Avg #2 =105.64

Avg #3 =105.64

Avg #4 =105.64

TIME=     8.00   MINS
T( 1)=   79.24   T( 2)=   106.32   T( 3)=   154.86   T( 4)=   161.22
T( 5)=  125.44   T( 6)=   101.78   T( 7)=    88.53   T( 8)=    82.64
T( 9)=   82.01   T(10)=    86.33   T(11)=    97.15   T(12)=   117.20
T(13)=  148.60   T(14)=   161.22   T(15)=   125.44   T(16)=   101.78
T(17)=   88.53   T(18)=    82.64   T(19)=    82.01   T(20)=    86.33
```

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T(21)= | 97.15 | T(22)= | 117.20 | T(23)= | 148.60 | T(24)= | 161.22 |
| T(25)= | 125.44 | T(26)= | 101.78 | T(27)= | 88.53 | T(28)= | 82.64 |
| T(29)= | 82.01 | T(30)= | 86.33 | T(31)= | 97.15 | T(32)= | 117.20 |
| T(33)= | 148.60 | T(34)= | 161.19 | T(35)= | 125.34 | T(36)= | 101.49 |
| T(37)= | 87.77 | T(38)= | 80.72 | T(39)= | 77.43 | T(40)= | 76.00 |
| T(41)= | 75.45 | T(42)= | 75.32 | T(43)= | 75.42 | T(44)= | 76.45 |
| T(45)= | 78.34 | T(46)= | 79.54 | | | | |

Avg top= 93.61

Avg #2 =109.09

Avg #3 =109.09

Avg #4 =109.09

TIME= 9.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.59 | T( 3)= | 155.55 | T( 4)= | 164.31 |
| T( 5)= | 129.67 | T( 6)= | 105.69 | T( 7)= | 91.54 | T( 8)= | 84.96 |
| T( 9)= | 84.22 | T(10)= | 89.04 | T(11)= | 100.69 | T(12)= | 121.25 |
| T(13)= | 152.01 | T(14)= | 164.31 | T(15)= | 129.67 | T(16)= | 105.69 |
| T(17)= | 91.54 | T(18)= | 84.96 | T(19)= | 84.22 | T(20)= | 89.04 |
| T(21)= | 100.69 | T(22)= | 121.25 | T(23)= | 152.01 | T(24)= | 164.31 |
| T(25)= | 129.67 | T(26)= | 105.69 | T(27)= | 91.54 | T(28)= | 84.96 |
| T(29)= | 84.22 | T(30)= | 89.04 | T(31)= | 100.69 | T(32)= | 121.25 |
| T(33)= | 152.01 | T(34)= | 164.26 | T(35)= | 129.51 | T(36)= | 105.24 |
| T(37)= | 90.43 | T(38)= | 82.34 | T(39)= | 78.29 | T(40)= | 76.44 |
| T(41)= | 75.67 | T(42)= | 75.44 | T(43)= | 75.52 | T(44)= | 76.60 |
| T(45)= | 78.56 | T(46)= | 79.78 | | | | |

Avg top= 95.31

Avg #2 =112.34

Avg #3 =112.34

Avg #4 =112.34

TIME= 10.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.67 | T( 3)= | 155.53 | T( 4)= | 166.55 |
| T( 5)= | 133.34 | T( 6)= | 109.35 | T( 7)= | 94.58 | T( 8)= | 87.46 |
| T( 9)= | 86.62 | T(10)= | 91.84 | T(11)= | 104.08 | T(12)= | 124.85 |
| T(13)= | 154.68 | T(14)= | 166.55 | T(15)= | 133.34 | T(16)= | 109.35 |
| T(17)= | 94.58 | T(18)= | 87.46 | T(19)= | 86.62 | T(20)= | 91.84 |
| T(21)= | 104.08 | T(22)= | 124.85 | T(23)= | 154.68 | T(24)= | 166.55 |
| T(25)= | 133.34 | T(26)= | 109.35 | T(27)= | 94.58 | T(28)= | 87.46 |
| T(29)= | 86.62 | T(30)= | 91.84 | T(31)= | 104.08 | T(32)= | 124.85 |
| T(33)= | 154.68 | T(34)= | 166.47 | T(35)= | 133.09 | T(36)= | 108.71 |
| T(37)= | 93.06 | T(38)= | 84.03 | T(39)= | 79.27 | T(40)= | 76.95 |
| T(41)= | 75.94 | T(42)= | 75.60 | T(43)= | 75.64 | T(44)= | 76.75 |
| T(45)= | 78.75 | T(46)= | 79.99 | | | | |

Avg top= 96.88

Avg #2 =115.33

Avg #3 =115.33

Avg #4 =115.33

TIME= 11.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.93 | T( 3)= | 156.45 | T( 4)= | 169.05 |
| T( 5)= | 136.70 | T( 6)= | 112.81 | T( 7)= | 97.62 | T( 8)= | 90.09 |
| T( 9)= | 89.17 | T(10)= | 94.68 | T(11)= | 107.34 | T(12)= | 128.19 |
| T(13)= | 157.43 | T(14)= | 169.05 | T(15)= | 136.70 | T(16)= | 112.81 |
| T(17)= | 97.62 | T(18)= | 90.09 | T(19)= | 89.17 | T(20)= | 94.68 |
| T(21)= | 107.34 | T(22)= | 128.19 | T(23)= | 157.43 | T(24)= | 169.05 |
| T(25)= | 136.70 | T(26)= | 112.81 | T(27)= | 97.62 | T(28)= | 90.09 |
| T(29)= | 89.17 | T(30)= | 94.68 | T(31)= | 107.34 | T(32)= | 128.19 |
| T(33)= | 157.43 | T(34)= | 168.93 | T(35)= | 136.34 | T(36)= | 111.93 |
| T(37)= | 95.63 | T(38)= | 85.78 | T(39)= | 80.33 | T(40)= | 77.55 |
| T(41)= | 76.26 | T(42)= | 75.79 | T(43)= | 75.78 | T(44)= | 76.90 |
| T(45)= | 78.93 | T(46)= | 80.17 | | | | |

Avg top= 98.43

Avg #2 =118.31

Avg #3 =118.31

Avg #4 =118.31

TIME= 12.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 107.09 | T( 3)= | 156.79 | T( 4)= | 171.02 |
| T( 5)= | 139.73 | T( 6)= | 116.08 | T( 7)= | 100.64 | T( 8)= | 92.81 |
| T( 9)= | 91.83 | T(10)= | 97.54 | T(11)= | 110.46 | T(12)= | 131.25 |
| T(13)= | 159.73 | T(14)= | 171.02 | T(15)= | 139.73 | T(16)= | 116.08 |
| T(17)= | 100.64 | T(18)= | 92.81 | T(19)= | 91.83 | T(20)= | 97.54 |
| T(21)= | 110.46 | T(22)= | 131.25 | T(23)= | 159.73 | T(24)= | 171.02 |
| T(25)= | 139.73 | T(26)= | 116.08 | T(27)= | 100.64 | T(28)= | 92.81 |
| T(29)= | 91.83 | T(30)= | 97.54 | T(31)= | 110.46 | T(32)= | 131.25 |
| T(33)= | 159.73 | T(34)= | 170.85 | T(35)= | 139.24 | T(36)= | 114.92 |
| T(37)= | 98.11 | T(38)= | 87.55 | T(39)= | 81.46 | T(40)= | 78.21 |
| T(41)= | 76.64 | T(42)= | 76.01 | T(43)= | 75.95 | T(44)= | 77.06 |
| T(45)= | 79.09 | T(46)= | 80.33 | | | | |

Avg top= 99.89

Avg #2 =121.11

Avg #3 =121.11

Avg #4 =121.11

TIME= 13.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.27 | T( 2)= | 107.12 | T( 3)= | 156.73 | T( 4)= | 172.51 |
| T( 5)= | 142.43 | T( 6)= | 119.16 | T( 7)= | 103.62 | T( 8)= | 95.59 |
| T( 9)= | 94.56 | T(10)= | 100.41 | T(11)= | 113.45 | T(12)= | 134.03 |
| T(13)= | 161.60 | T(14)= | 172.51 | T(15)= | 142.43 | T(16)= | 119.16 |
| T(17)= | 103.62 | T(18)= | 95.59 | T(19)= | 94.56 | T(20)= | 100.41 |
| T(21)= | 113.45 | T(22)= | 134.03 | T(23)= | 161.60 | T(24)= | 172.51 |

```
T(25)=  142.43  T(26)=  119.16  T(27)=  103.62  T(28)=   95.59
T(29)=   94.56  T(30)=  100.41  T(31)=  113.45  T(32)=  134.03
T(33)=  161.60  T(34)=  172.28  T(35)=  141.78  T(36)=  117.67
T(37)=  100.50  T(38)=   89.33  T(39)=   82.65  T(40)=   78.94
T(41)=   77.07  T(42)=   76.27  T(43)=   76.14  T(44)=   77.23
T(45)=   79.25  T(46)=   80.48
Avg top=101.26

Avg #2 =123.74

Avg #3 =123.74

Avg #4 =123.74

TIME=   14.00   MINS
T( 1)=   79.26  T( 2)=  107.04  T( 3)=  156.39  T( 4)=  173.61
T( 5)=  144.82  T( 6)=  122.05  T( 7)=  106.55  T( 8)=   98.40
T( 9)=   97.34  T(10)=  103.25  T(11)=  116.31  T(12)=  136.54
T(13)=  163.11  T(14)=  173.61  T(15)=  144.82  T(16)=  122.05
T(17)=  106.55  T(18)=   98.40  T(19)=   97.34  T(20)=  103.25
T(21)=  116.31  T(22)=  136.54  T(23)=  163.11  T(24)=  173.61
T(25)=  144.82  T(26)=  122.05  T(27)=  106.55  T(28)=   98.40
T(29)=   97.34  T(30)=  103.25  T(31)=  116.31  T(32)=  136.54
T(33)=  163.11  T(34)=  173.31  T(35)=  143.98  T(36)=  120.20
T(37)=  102.78  T(38)=   91.10  T(39)=   83.87  T(40)=   79.73
T(41)=   77.55  T(42)=   76.57  T(43)=   76.36  T(44)=   77.42
T(45)=   79.41  T(46)=   80.61
Avg top=102.55

Avg #2 =126.20

Avg #3 =126.20

Avg #4 =126.20

TIME=   15.00   MINS
T( 1)=   79.26  T( 2)=  106.91  T( 3)=  155.99  T( 4)=  174.46
T( 5)=  146.94  T( 6)=  124.76  T( 7)=  109.40  T( 8)=  101.22
T( 9)=  100.13  T(10)=  106.05  T(11)=  119.02  T(12)=  138.83
T(13)=  164.38  T(14)=  174.46  T(15)=  146.94  T(16)=  124.76
T(17)=  109.40  T(18)=  101.22  T(19)=  100.13  T(20)=  106.05
T(21)=  119.02  T(22)=  138.83  T(23)=  164.38  T(24)=  174.46
T(25)=  146.94  T(26)=  124.76  T(27)=  109.40  T(28)=  101.22
T(29)=  100.13  T(30)=  106.05  T(31)=  119.02  T(32)=  138.83
T(33)=  164.38  T(34)=  174.08  T(35)=  145.89  T(36)=  122.51
T(37)=  104.95  T(38)=   92.85  T(39)=   85.13  T(40)=   80.56
T(41)=   78.07  T(42)=   76.91  T(43)=   76.61  T(44)=   77.63
T(45)=   79.56  T(46)=   80.74
Avg top=103.76

Avg #2 =128.52

Avg #3 =128.52
```

Avg #4 =128.52

TIME= 16.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.80 | T( 3)= | 155.72 | T( 4)= | 175.24 |
| T( 5)= | 148.86 | T( 6)= | 127.31 | T( 7)= | 112.18 | T( 8)= | 104.02 |
| T( 9)= | 102.91 | T(10)= | 108.80 | T(11)= | 121.61 | T(12)= | 140.93 |
| T(13)= | 165.54 | T(14)= | 175.24 | T(15)= | 148.86 | T(16)= | 127.31 |
| T(17)= | 112.18 | T(18)= | 104.02 | T(19)= | 102.91 | T(20)= | 108.80 |
| T(21)= | 121.61 | T(22)= | 140.93 | T(23)= | 165.54 | T(24)= | 175.24 |
| T(25)= | 148.86 | T(26)= | 127.31 | T(27)= | 112.18 | T(28)= | 104.02 |
| T(29)= | 102.91 | T(30)= | 108.80 | T(31)= | 121.61 | T(32)= | 140.93 |
| T(33)= | 165.54 | T(34)= | 174.77 | T(35)= | 147.58 | T(36)= | 124.63 |
| T(37)= | 107.01 | T(38)= | 94.55 | T(39)= | 86.39 | T(40)= | 81.43 |
| T(41)= | 78.64 | T(42)= | 77.29 | T(43)= | 76.89 | T(44)= | 77.86 |
| T(45)= | 79.72 | T(46)= | 80.86 | | | | |

Avg top=104.92

Avg #2 =130.74

Avg #3 =130.74

Avg #4 =130.74

TIME= 17.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.70 | T( 3)= | 155.46 | T( 4)= | 175.93 |
| T( 5)= | 150.62 | T( 6)= | 129.72 | T( 7)= | 114.87 | T( 8)= | 106.79 |
| T( 9)= | 105.67 | T(10)= | 111.49 | T(11)= | 124.08 | T(12)= | 142.88 |
| T(13)= | 166.58 | T(14)= | 175.93 | T(15)= | 150.62 | T(16)= | 129.72 |
| T(17)= | 114.87 | T(18)= | 106.79 | T(19)= | 105.67 | T(20)= | 111.49 |
| T(21)= | 124.08 | T(22)= | 142.88 | T(23)= | 166.58 | T(24)= | 175.93 |
| T(25)= | 150.62 | T(26)= | 129.72 | T(27)= | 114.87 | T(28)= | 106.79 |
| T(29)= | 105.67 | T(30)= | 111.49 | T(31)= | 124.08 | T(32)= | 142.88 |
| T(33)= | 166.58 | T(34)= | 175.35 | T(35)= | 149.08 | T(36)= | 126.57 |
| T(37)= | 108.95 | T(38)= | 96.22 | T(39)= | 87.67 | T(40)= | 82.33 |
| T(41)= | 79.25 | T(42)= | 77.71 | T(43)= | 77.20 | T(44)= | 78.11 |
| T(45)= | 79.89 | T(46)= | 80.98 | | | | |

Avg top=106.03

Avg #2 =132.86

Avg #3 =132.86

Avg #4 =132.86

TIME= 18.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.63 | T( 3)= | 155.28 | T( 4)= | 176.59 |
| T( 5)= | 152.24 | T( 6)= | 131.99 | T( 7)= | 117.47 | T( 8)= | 109.51 |
| T( 9)= | 108.39 | T(10)= | 114.11 | T(11)= | 126.44 | T(12)= | 144.71 |
| T(13)= | 167.57 | T(14)= | 176.59 | T(15)= | 152.24 | T(16)= | 131.99 |
| T(17)= | 117.47 | T(18)= | 109.51 | T(19)= | 108.39 | T(20)= | 114.11 |
| T(21)= | 126.44 | T(22)= | 144.71 | T(23)= | 167.57 | T(24)= | 176.59 |
| T(25)= | 152.24 | T(26)= | 131.99 | T(27)= | 117.47 | T(28)= | 109.51 |

```
T(29)=  108.39  T(30)=  114.11  T(31)=  126.44  T(32)=  144.71
T(33)=  167.57  T(34)=  175.90  T(35)=  150.43  T(36)=  128.36
T(37)=  110.79  T(38)=   97.83  T(39)=   88.94  T(40)=   83.25
T(41)=   79.90  T(42)=   78.16  T(43)=   77.55  T(44)=   78.38
T(45)=   80.06  T(46)=   81.10
Avg top=107.11

Avg #2 =134.90

Avg #3 =134.90

Avg #4 =134.90

TIME=   19.00   MINS
T( 1)=   79.25  T( 2)=  106.70  T( 3)=  155.64  T( 4)=  177.56
T( 5)=  153.85  T( 6)=  134.18  T( 7)=  120.00  T( 8)=  112.17
T( 9)=  111.06  T(10)=  116.67  T(11)=  128.72  T(12)=  146.49
T(13)=  168.76  T(14)=  177.56  T(15)=  153.85  T(16)=  134.18
T(17)=  120.00  T(18)=  112.17  T(19)=  111.06  T(20)=  116.67
T(21)=  128.72  T(22)=  146.49  T(23)=  168.76  T(24)=  177.56
T(25)=  153.85  T(26)=  134.18  T(27)=  120.00  T(28)=  112.17
T(29)=  111.06  T(30)=  116.67  T(31)=  128.72  T(32)=  146.49
T(33)=  168.76  T(34)=  176.75  T(35)=  151.74  T(36)=  130.03
T(37)=  112.53  T(38)=   99.40  T(39)=   90.21  T(40)=   84.20
T(41)=   80.57  T(42)=   78.64  T(43)=   77.93  T(44)=   78.68
T(45)=   80.24  T(46)=   81.22
Avg top=108.20

Avg #2 =136.95

Avg #3 =136.95

Avg #4 =136.95

TIME=   20.00   MINS
T( 1)=   79.26  T( 2)=  106.86  T( 3)=  156.13  T( 4)=  178.65
T( 5)=  155.45  T( 6)=  136.29  T( 7)=  122.45  T( 8)=  114.78
T( 9)=  113.68  T(10)=  119.17  T(11)=  130.93  T(12)=  148.26
T(13)=  170.03  T(14)=  178.65  T(15)=  155.45  T(16)=  136.29
T(17)=  122.45  T(18)=  114.78  T(19)=  113.68  T(20)=  119.17
T(21)=  130.93  T(22)=  148.26  T(23)=  170.03  T(24)=  178.65
T(25)=  155.45  T(26)=  136.29  T(27)=  122.45  T(28)=  114.78
T(29)=  113.68  T(30)=  119.17  T(31)=  130.93  T(32)=  148.26
T(33)=  170.03  T(34)=  177.70  T(35)=  153.03  T(36)=  131.62
T(37)=  114.18  T(38)=  100.91  T(39)=   91.46  T(40)=   85.16
T(41)=   81.27  T(42)=   79.16  T(43)=   78.34  T(44)=   79.00
T(45)=   80.44  T(46)=   81.35
Avg top=109.28

Avg #2 =138.97

Avg #3 =138.97
```

Avg #4 =138.97

TIME= 21.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.99 | T( 3)= | 156.47 | T( 4)= | 179.66 |
| T( 5)= | 157.03 | T( 6)= | 138.35 | T( 7)= | 124.84 | T( 8)= | 117.33 |
| T( 9)= | 116.24 | T(10)= | 121.60 | T(11)= | 133.08 | T(12)= | 149.99 |
| T(13)= | 171.24 | T(14)= | 179.66 | T(15)= | 157.03 | T(16)= | 138.35 |
| T(17)= | 124.84 | T(18)= | 117.33 | T(19)= | 116.24 | T(20)= | 121.60 |
| T(21)= | 133.08 | T(22)= | 149.99 | T(23)= | 171.24 | T(24)= | 179.66 |
| T(25)= | 157.03 | T(26)= | 138.35 | T(27)= | 124.84 | T(28)= | 117.33 |
| T(29)= | 116.24 | T(30)= | 121.60 | T(31)= | 133.08 | T(32)= | 149.99 |
| T(33)= | 171.24 | T(34)= | 178.58 | T(35)= | 154.28 | T(36)= | 133.13 |
| T(37)= | 115.76 | T(38)= | 102.38 | T(39)= | 92.70 | T(40)= | 86.13 |
| T(41)= | 82.00 | T(42)= | 79.70 | T(43)= | 78.78 | T(44)= | 79.34 |
| T(45)= | 80.64 | T(46)= | 81.49 | | | | |

Avg top=110.34

Avg #2 =140.94

Avg #3 =140.94

Avg #4 =140.94

TIME= 22.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 107.02 | T( 3)= | 156.45 | T( 4)= | 180.41 |
| T( 5)= | 158.51 | T( 6)= | 140.34 | T( 7)= | 127.16 | T( 8)= | 119.82 |
| T( 9)= | 118.75 | T(10)= | 123.98 | T(11)= | 135.18 | T(12)= | 151.64 |
| T(13)= | 172.24 | T(14)= | 180.41 | T(15)= | 158.51 | T(16)= | 140.34 |
| T(17)= | 127.16 | T(18)= | 119.82 | T(19)= | 118.75 | T(20)= | 123.98 |
| T(21)= | 135.18 | T(22)= | 151.64 | T(23)= | 172.24 | T(24)= | 180.41 |
| T(25)= | 158.51 | T(26)= | 140.34 | T(27)= | 127.16 | T(28)= | 119.82 |
| T(29)= | 118.75 | T(30)= | 123.98 | T(31)= | 135.18 | T(32)= | 151.64 |
| T(33)= | 172.24 | T(34)= | 179.18 | T(35)= | 155.43 | T(36)= | 134.56 |
| T(37)= | 117.28 | T(38)= | 103.81 | T(39)= | 93.92 | T(40)= | 87.11 |
| T(41)= | 82.75 | T(42)= | 80.28 | T(43)= | 79.24 | T(44)= | 79.71 |
| T(45)= | 80.86 | T(46)= | 81.63 | | | | |

Avg top=111.36

Avg #2 =142.80

Avg #3 =142.80

Avg #4 =142.80

TIME= 23.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.98 | T( 3)= | 156.28 | T( 4)= | 181.00 |
| T( 5)= | 159.89 | T( 6)= | 142.25 | T( 7)= | 129.41 | T( 8)= | 122.25 |
| T( 9)= | 121.19 | T(10)= | 126.29 | T(11)= | 137.20 | T(12)= | 153.19 |
| T(13)= | 173.10 | T(14)= | 181.00 | T(15)= | 159.89 | T(16)= | 142.25 |
| T(17)= | 129.41 | T(18)= | 122.25 | T(19)= | 121.19 | T(20)= | 126.29 |
| T(21)= | 137.20 | T(22)= | 153.19 | T(23)= | 173.10 | T(24)= | 181.00 |
| T(25)= | 159.89 | T(26)= | 142.25 | T(27)= | 129.41 | T(28)= | 122.25 |
| T(29)= | 121.19 | T(30)= | 126.29 | T(31)= | 137.20 | T(32)= | 153.19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T(33)= | 173.10 | T(34)= | 179.62 | T(35)= | 156.46 | T(36)= | 135.90 |
| T(37)= | 118.73 | T(38)= | 105.19 | T(39)= | 95.13 | T(40)= | 88.09 |
| T(41)= | 83.52 | T(42)= | 80.88 | T(43)= | 79.74 | T(44)= | 80.10 |
| T(45)= | 81.09 | T(46)= | 81.77 | | | | |

Avg top=112.33

Avg #2 =144.58

Avg #3 =144.58

Avg #4 =144.58

TIME= 24.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.89 | T( 3)= | 155.99 | T( 4)= | 181.43 |
| T( 5)= | 161.16 | T( 6)= | 144.08 | T( 7)= | 131.60 | T( 8)= | 124.61 |
| T( 9)= | 123.58 | T(10)= | 128.53 | T(11)= | 139.14 | T(12)= | 154.65 |
| T(13)= | 173.82 | T(14)= | 181.43 | T(15)= | 161.16 | T(16)= | 144.08 |
| T(17)= | 131.60 | T(18)= | 124.61 | T(19)= | 123.58 | T(20)= | 128.53 |
| T(21)= | 139.14 | T(22)= | 154.65 | T(23)= | 173.82 | T(24)= | 181.43 |
| T(25)= | 161.16 | T(26)= | 144.08 | T(27)= | 131.60 | T(28)= | 124.61 |
| T(29)= | 123.58 | T(30)= | 128.53 | T(31)= | 139.14 | T(32)= | 154.65 |
| T(33)= | 173.82 | T(34)= | 179.90 | T(35)= | 157.38 | T(36)= | 137.16 |
| T(37)= | 120.11 | T(38)= | 106.53 | T(39)= | 96.31 | T(40)= | 89.07 |
| T(41)= | 84.30 | T(42)= | 81.50 | T(43)= | 80.26 | T(44)= | 80.51 |
| T(45)= | 81.33 | T(46)= | 81.93 | | | | |

Avg top=113.25

Avg #2 =146.26

Avg #3 =146.26

Avg #4 =146.26

TIME= 25.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.26 | T( 2)= | 106.78 | T( 3)= | 155.68 | T( 4)= | 181.78 |
| T( 5)= | 162.33 | T( 6)= | 145.82 | T( 7)= | 133.71 | T( 8)= | 126.91 |
| T( 9)= | 125.90 | T(10)= | 130.71 | T(11)= | 141.01 | T(12)= | 156.02 |
| T(13)= | 174.46 | T(14)= | 181.78 | T(15)= | 162.33 | T(16)= | 145.82 |
| T(17)= | 133.71 | T(18)= | 126.91 | T(19)= | 125.90 | T(20)= | 130.71 |
| T(21)= | 141.01 | T(22)= | 156.02 | T(23)= | 174.46 | T(24)= | 181.78 |
| T(25)= | 162.33 | T(26)= | 145.82 | T(27)= | 133.71 | T(28)= | 126.91 |
| T(29)= | 125.90 | T(30)= | 130.71 | T(31)= | 141.01 | T(32)= | 156.02 |
| T(33)= | 174.46 | T(34)= | 180.09 | T(35)= | 158.19 | T(36)= | 138.33 |
| T(37)= | 121.42 | T(38)= | 107.82 | T(39)= | 97.47 | T(40)= | 90.05 |
| T(41)= | 85.10 | T(42)= | 82.14 | T(43)= | 80.81 | T(44)= | 80.94 |
| T(45)= | 81.58 | T(46)= | 82.09 | | | | |

Avg top=114.14

Avg #2 =147.87

Avg #3 =147.87

Avg #4 =147.87

TIME= 26.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.67 | T( 3)= | 155.36 | T( 4)= | 182.07 |
| T( 5)= | 163.42 | T( 6)= | 147.49 | T( 7)= | 135.75 | T( 8)= | 129.14 |
| T( 9)= | 128.15 | T(10)= | 132.82 | T(11)= | 142.81 | T(12)= | 157.30 |
| T(13)= | 175.03 | T(14)= | 182.07 | T(15)= | 163.42 | T(16)= | 147.49 |
| T(17)= | 135.75 | T(18)= | 129.14 | T(19)= | 128.15 | T(20)= | 132.82 |
| T(21)= | 142.81 | T(22)= | 157.30 | T(23)= | 175.03 | T(24)= | 182.07 |
| T(25)= | 163.42 | T(26)= | 147.49 | T(27)= | 135.75 | T(28)= | 129.14 |
| T(29)= | 128.15 | T(30)= | 132.82 | T(31)= | 142.81 | T(32)= | 157.30 |
| T(33)= | 175.03 | T(34)= | 180.21 | T(35)= | 158.91 | T(36)= | 139.42 |
| T(37)= | 122.67 | T(38)= | 109.07 | T(39)= | 98.61 | T(40)= | 91.03 |
| T(41)= | 85.90 | T(42)= | 82.81 | T(43)= | 81.38 | T(44)= | 81.39 |
| T(45)= | 81.85 | T(46)= | 82.26 | | | | |

Avg top=115.00

Avg #2 =149.40

Avg #3 =149.40

Avg #4 =149.40

TIME= 27.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.56 | T( 3)= | 155.04 | T( 4)= | 182.31 |
| T( 5)= | 164.42 | T( 6)= | 149.08 | T( 7)= | 137.72 | T( 8)= | 131.31 |
| T( 9)= | 130.34 | T(10)= | 134.86 | T(11)= | 144.53 | T(12)= | 158.51 |
| T(13)= | 175.54 | T(14)= | 182.31 | T(15)= | 164.42 | T(16)= | 149.08 |
| T(17)= | 137.72 | T(18)= | 131.31 | T(19)= | 130.34 | T(20)= | 134.86 |
| T(21)= | 144.53 | T(22)= | 158.51 | T(23)= | 175.54 | T(24)= | 182.31 |
| T(25)= | 164.42 | T(26)= | 149.08 | T(27)= | 137.72 | T(28)= | 131.31 |
| T(29)= | 130.34 | T(30)= | 134.86 | T(31)= | 144.53 | T(32)= | 158.51 |
| T(33)= | 175.54 | T(34)= | 180.29 | T(35)= | 159.56 | T(36)= | 140.44 |
| T(37)= | 123.86 | T(38)= | 110.28 | T(39)= | 99.73 | T(40)= | 92.00 |
| T(41)= | 86.72 | T(42)= | 83.49 | T(43)= | 81.97 | T(44)= | 81.85 |
| T(45)= | 82.13 | T(46)= | 82.44 | | | | |

Avg top=115.83

Avg #2 =150.86

Avg #3 =150.86

Avg #4 =150.86

TIME= 28.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.25 | T( 2)= | 106.44 | T( 3)= | 154.72 | T( 4)= | 182.51 |
| T( 5)= | 165.37 | T( 6)= | 150.59 | T( 7)= | 139.61 | T( 8)= | 133.40 |
| T( 9)= | 132.45 | T(10)= | 136.84 | T(11)= | 146.17 | T(12)= | 159.65 |
| T(13)= | 176.00 | T(14)= | 182.51 | T(15)= | 165.37 | T(16)= | 150.59 |
| T(17)= | 139.61 | T(18)= | 133.40 | T(19)= | 132.45 | T(20)= | 136.84 |
| T(21)= | 146.17 | T(22)= | 159.65 | T(23)= | 176.00 | T(24)= | 182.51 |
| T(25)= | 165.37 | T(26)= | 150.59 | T(27)= | 139.61 | T(28)= | 133.40 |
| T(29)= | 132.45 | T(30)= | 136.84 | T(31)= | 146.17 | T(32)= | 159.65 |
| T(33)= | 176.00 | T(34)= | 180.32 | T(35)= | 160.13 | T(36)= | 141.38 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T(37)= | 124.99 | T(38)= | 111.45 | T(39)= | 100.83 | T(40)= | 92.97 |
| T(41)= | 87.54 | T(42)= | 84.18 | T(43)= | 82.58 | T(44)= | 82.34 |
| T(45)= | 82.42 | T(46)= | 82.63 | | | | |

Avg top=116.64

Avg #2 =152.26

Avg #3 =152.26

Avg #4 =152.26

TIME= 29.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.24 | T( 2)= | 106.33 | T( 3)= | 154.44 | T( 4)= | 182.70 |
| T( 5)= | 166.25 | T( 6)= | 152.03 | T( 7)= | 141.43 | T( 8)= | 135.42 |
| T( 9)= | 134.50 | T(10)= | 138.74 | T(11)= | 147.75 | T(12)= | 160.74 |
| T(13)= | 176.44 | T(14)= | 182.70 | T(15)= | 166.25 | T(16)= | 152.03 |
| T(17)= | 141.43 | T(18)= | 135.42 | T(19)= | 134.50 | T(20)= | 138.74 |
| T(21)= | 147.75 | T(22)= | 160.74 | T(23)= | 176.44 | T(24)= | 182.70 |
| T(25)= | 166.25 | T(26)= | 152.03 | T(27)= | 141.43 | T(28)= | 135.42 |
| T(29)= | 134.50 | T(30)= | 138.74 | T(31)= | 147.75 | T(32)= | 160.74 |
| T(33)= | 176.44 | T(34)= | 180.35 | T(35)= | 160.65 | T(36)= | 142.25 |
| T(37)= | 126.06 | T(38)= | 112.57 | T(39)= | 101.90 | T(40)= | 93.93 |
| T(41)= | 88.37 | T(42)= | 84.89 | T(43)= | 83.20 | T(44)= | 82.84 |
| T(45)= | 82.72 | T(46)= | 82.83 | | | | |

Avg top=117.42

Avg #2 =153.60

Avg #3 =153.60

Avg #4 =153.60

TIME= 30.00 MINS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T( 1)= | 79.24 | T( 2)= | 106.24 | T( 3)= | 154.22 | T( 4)= | 182.90 |
| T( 5)= | 167.09 | T( 6)= | 153.41 | T( 7)= | 143.19 | T( 8)= | 137.38 |
| T( 9)= | 136.48 | T(10)= | 140.57 | T(11)= | 149.27 | T(12)= | 161.77 |
| T(13)= | 176.88 | T(14)= | 182.90 | T(15)= | 167.09 | T(16)= | 153.41 |
| T(17)= | 143.19 | T(18)= | 137.38 | T(19)= | 136.48 | T(20)= | 140.57 |
| T(21)= | 149.27 | T(22)= | 161.77 | T(23)= | 176.88 | T(24)= | 182.90 |
| T(25)= | 167.09 | T(26)= | 153.41 | T(27)= | 143.19 | T(28)= | 137.38 |
| T(29)= | 136.48 | T(30)= | 140.57 | T(31)= | 149.27 | T(32)= | 161.77 |
| T(33)= | 176.88 | T(34)= | 180.39 | T(35)= | 161.13 | T(36)= | 143.08 |
| T(37)= | 127.08 | T(38)= | 113.65 | T(39)= | 102.95 | T(40)= | 94.88 |
| T(41)= | 89.20 | T(42)= | 85.62 | T(43)= | 83.84 | T(44)= | 83.35 |
| T(45)= | 83.03 | T(46)= | 83.03 | | | | |

Avg top=118.18

Avg #2 =154.89

Avg #3 =154.89

Avg #4 =154.89

| TN 1 | TN 2 | TN 3 | TN 4 | TN 5 | TN 6 |
|---|---|---|---|---|---|
| 78.2 | 76.6 | 75.2 | 74.8 | 75.0 | 75.0 |
| 78.8 | 90.0 | 123.5 | 107.3 | 82.5 | 76.8 |
| 79.0 | 98.8 | 142.7 | 127.4 | 91.9 | 80.0 |
| 79.2 | 103.3 | 150.7 | 140.3 | 100.9 | 84.2 |
| 79.2 | 105.0 | 152.8 | 148.0 | 108.7 | 88.8 |
| 79.2 | 105.6 | 153.1 | 153.2 | 115.1 | 93.3 |
| 79.2 | 106.0 | 153.9 | 157.5 | 120.6 | 97.6 |
| 79.2 | 106.3 | 154.9 | 161.2 | 125.4 | 101.8 |
| 79.3 | 106.6 | 155.5 | 164.3 | 129.7 | 105.7 |
| 79.3 | 106.7 | 155.5 | 166.6 | 133.3 | 109.4 |
| 79.3 | 106.9 | 156.4 | 169.0 | 136.7 | 112.8 |
| 79.3 | 107.1 | 156.8 | 171.0 | 139.7 | 116.1 |
| 79.3 | 107.1 | 156.7 | 172.5 | 142.4 | 119.2 |
| 79.3 | 107.0 | 156.4 | 173.6 | 144.8 | 122.0 |
| 79.3 | 106.9 | 156.0 | 174.5 | 146.9 | 124.8 |
| 79.3 | 106.8 | 155.7 | 175.2 | 148.9 | 127.3 |
| 79.3 | 106.7 | 155.5 | 175.9 | 150.6 | 129.7 |
| 79.3 | 106.6 | 155.3 | 176.6 | 152.2 | 132.0 |
| 79.3 | 106.7 | 155.6 | 177.6 | 153.9 | 134.2 |
| 79.3 | 106.9 | 156.1 | 178.6 | 155.5 | 136.3 |
| 79.3 | 107.0 | 156.5 | 179.7 | 157.0 | 138.3 |
| 79.3 | 107.0 | 156.4 | 180.4 | 158.5 | 140.3 |
| 79.3 | 107.0 | 156.3 | 181.0 | 159.9 | 142.2 |
| 79.3 | 106.9 | 156.0 | 181.4 | 161.2 | 144.1 |
| 79.3 | 106.8 | 155.7 | 181.8 | 162.3 | 145.8 |
| 79.3 | 106.7 | 155.4 | 182.1 | 163.4 | 147.5 |
| 79.3 | 106.6 | 155.0 | 182.3 | 164.4 | 149.1 |
| 79.2 | 106.4 | 154.7 | 182.5 | 165.4 | 150.6 |
| 79.2 | 106.3 | 154.4 | 182.7 | 166.3 | 152.0 |
| 79.2 | 106.2 | 154.2 | 182.9 | 167.1 | 153.4 |

| TN 7 | TN 8 | TN 9 | TN 10 | TN 11 | TN 12 |
|---|---|---|---|---|---|
| 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| 75.4 | 75.1 | 75.1 | 75.3 | 76.3 | 80.6 |
| 76.5 | 75.5 | 75.4 | 76.1 | 78.9 | 88.0 |
| 78.1 | 76.2 | 76.0 | 77.4 | 82.2 | 95.3 |
| 80.3 | 77.3 | 77.0 | 79.2 | 85.9 | 101.9 |
| 82.8 | 78.7 | 78.4 | 81.4 | 89.7 | 107.7 |
| 85.6 | 80.5 | 80.0 | 83.7 | 93.5 | 112.7 |
| 88.5 | 82.6 | 82.0 | 86.3 | 97.1 | 117.2 |
| 91.5 | 85.0 | 84.2 | 89.0 | 100.7 | 121.3 |
| 94.6 | 87.5 | 86.6 | 91.8 | 104.1 | 124.9 |
| 97.6 | 90.1 | 89.2 | 94.7 | 107.3 | 128.2 |
| 100.6 | 92.8 | 91.8 | 97.5 | 110.5 | 131.2 |
| 103.6 | 95.6 | 94.6 | 100.4 | 113.5 | 134.0 |
| 106.5 | 98.4 | 97.3 | 103.2 | 116.3 | 136.5 |
| 109.4 | 101.2 | 100.1 | 106.0 | 119.0 | 138.8 |
| 112.2 | 104.0 | 102.9 | 108.8 | 121.6 | 140.9 |
| 114.9 | 106.8 | 105.7 | 111.5 | 124.1 | 142.9 |
| 117.5 | 109.5 | 108.4 | 114.1 | 126.4 | 144.7 |
| 120.0 | 112.2 | 111.1 | 116.7 | 128.7 | 146.5 |
| 122.5 | 114.8 | 113.7 | 119.2 | 130.9 | 148.3 |

| | | | | | |
|---|---|---|---|---|---|
| 124.8 | 117.3 | 116.2 | 121.6 | 133.1 | 150.0 |
| 127.2 | 119.8 | 118.7 | 124.0 | 135.2 | 151.6 |
| 129.4 | 122.3 | 121.2 | 126.3 | 137.2 | 153.2 |
| 131.6 | 124.6 | 123.6 | 128.5 | 139.1 | 154.7 |
| 133.7 | 126.9 | 125.9 | 130.7 | 141.0 | 156.0 |
| 135.8 | 129.1 | 128.1 | 132.8 | 142.8 | 157.3 |
| 137.7 | 131.3 | 130.3 | 134.9 | 144.5 | 158.5 |
| 139.6 | 133.4 | 132.5 | 136.8 | 146.2 | 159.7 |
| 141.4 | 135.4 | 134.5 | 138.7 | 147.8 | 160.7 |
| 143.2 | 137.4 | 136.5 | 140.6 | 149.3 | 161.8 |

| TN 13 | TN 14 | TN 15 | TN 16 | TN 17 | TN 18 |
|---|---|---|---|---|---|
| 74.9 | 74.8 | 75.0 | 75.0 | 75.0 | 75.0 |
| 99.2 | 107.3 | 82.5 | 76.8 | 75.4 | 75.1 |
| 115.6 | 127.4 | 91.9 | 80.0 | 76.5 | 75.5 |
| 127.0 | 140.3 | 100.9 | 84.2 | 78.1 | 76.2 |
| 134.6 | 148.0 | 108.7 | 88.8 | 80.3 | 77.3 |
| 140.0 | 153.2 | 115.1 | 93.3 | 82.8 | 78.7 |
| 144.6 | 157.5 | 120.6 | 97.6 | 85.6 | 80.5 |
| 148.6 | 161.2 | 125.4 | 101.8 | 88.5 | 82.6 |
| 152.0 | 164.3 | 129.7 | 105.7 | 91.5 | 85.0 |
| 154.7 | 166.6 | 133.3 | 109.4 | 94.6 | 87.5 |
| 157.4 | 169.0 | 136.7 | 112.8 | 97.6 | 90.1 |
| 159.7 | 171.0 | 139.7 | 116.1 | 100.6 | 92.8 |
| 161.6 | 172.5 | 142.4 | 119.2 | 103.6 | 95.6 |
| 163.1 | 173.6 | 144.8 | 122.0 | 106.5 | 98.4 |
| 164.4 | 174.5 | 146.9 | 124.8 | 109.4 | 101.2 |
| 165.5 | 175.2 | 148.9 | 127.3 | 112.2 | 104.0 |
| 166.6 | 175.9 | 150.6 | 129.7 | 114.9 | 106.8 |
| 167.6 | 176.6 | 152.2 | 132.0 | 117.5 | 109.5 |
| 168.8 | 177.6 | 153.9 | 134.2 | 120.0 | 112.2 |
| 170.0 | 178.6 | 155.5 | 136.3 | 122.5 | 114.8 |
| 171.2 | 179.7 | 157.0 | 138.3 | 124.8 | 117.3 |
| 172.2 | 180.4 | 158.5 | 140.3 | 127.2 | 119.8 |
| 173.1 | 181.0 | 159.9 | 142.2 | 129.4 | 122.3 |
| 173.8 | 181.4 | 161.2 | 144.1 | 131.6 | 124.6 |
| 174.5 | 181.8 | 162.3 | 145.8 | 133.7 | 126.9 |
| 175.0 | 182.1 | 163.4 | 147.5 | 135.8 | 129.1 |
| 175.5 | 182.3 | 164.4 | 149.1 | 137.7 | 131.3 |
| 176.0 | 182.5 | 165.4 | 150.6 | 139.6 | 133.4 |
| 176.4 | 182.7 | 166.3 | 152.0 | 141.4 | 135.4 |
| 176.9 | 182.9 | 167.1 | 153.4 | 143.2 | 137.4 |

| TN 19 | TN 20 | TN 21 | TN 22 | TN 23 | TN 24 |
|---|---|---|---|---|---|
| 75.0 | 75.0 | 75.0 | 75.0 | 74.9 | 74.8 |
| 75.1 | 75.3 | 76.3 | 80.6 | 99.2 | 107.3 |
| 75.4 | 76.1 | 78.9 | 88.0 | 115.6 | 127.4 |
| 76.0 | 77.4 | 82.2 | 95.3 | 127.0 | 140.3 |
| 77.0 | 79.2 | 85.9 | 101.9 | 134.6 | 148.0 |
| 78.4 | 81.4 | 89.7 | 107.7 | 140.0 | 153.2 |
| 80.0 | 83.7 | 93.5 | 112.7 | 144.6 | 157.5 |
| 82.0 | 86.3 | 97.1 | 117.2 | 148.6 | 161.2 |
| 84.2 | 89.0 | 100.7 | 121.3 | 152.0 | 164.3 |

| | | | | | |
|---|---|---|---|---|---|
| 86.6 | 91.8 | 104.1 | 124.9 | 154.7 | 166.6 |
| 89.2 | 94.7 | 107.3 | 128.2 | 157.4 | 169.0 |
| 91.8 | 97.5 | 110.5 | 131.2 | 159.7 | 171.0 |
| 94.6 | 100.4 | 113.5 | 134.0 | 161.6 | 172.5 |
| 97.3 | 103.2 | 116.3 | 136.5 | 163.1 | 173.6 |
| 100.1 | 106.0 | 119.0 | 138.8 | 164.4 | 174.5 |
| 102.9 | 108.8 | 121.6 | 140.9 | 165.5 | 175.2 |
| 105.7 | 111.5 | 124.1 | 142.9 | 166.6 | 175.9 |
| 108.4 | 114.1 | 126.4 | 144.7 | 167.6 | 176.6 |
| 111.1 | 116.7 | 128.7 | 146.5 | 168.8 | 177.6 |
| 113.7 | 119.2 | 130.9 | 148.3 | 170.0 | 178.6 |
| 116.2 | 121.6 | 133.1 | 150.0 | 171.2 | 179.7 |
| 118.7 | 124.0 | 135.2 | 151.6 | 172.2 | 180.4 |
| 121.2 | 126.3 | 137.2 | 153.2 | 173.1 | 181.0 |
| 123.6 | 128.5 | 139.1 | 154.7 | 173.8 | 181.4 |
| 125.9 | 130.7 | 141.0 | 156.0 | 174.5 | 181.8 |
| 128.1 | 132.8 | 142.8 | 157.3 | 175.0 | 182.1 |
| 130.3 | 134.9 | 144.5 | 158.5 | 175.5 | 182.3 |
| 132.5 | 136.8 | 146.2 | 159.7 | 176.0 | 182.5 |
| 134.5 | 138.7 | 147.8 | 160.7 | 176.4 | 182.7 |
| 136.5 | 140.6 | 149.3 | 161.8 | 176.9 | 182.9 |

| TN 25 | TN 26 | TN 27 | TN 28 | TN 29 | TN 30 |
|---|---|---|---|---|---|
| 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| 82.5 | 76.8 | 75.4 | 75.1 | 75.1 | 75.3 |
| 91.9 | 80.0 | 76.5 | 75.5 | 75.4 | 76.1 |
| 100.9 | 84.2 | 78.1 | 76.2 | 76.0 | 77.4 |
| 108.7 | 88.8 | 80.3 | 77.3 | 77.0 | 79.2 |
| 115.1 | 93.3 | 82.8 | 78.7 | 78.4 | 81.4 |
| 120.6 | 97.6 | 85.6 | 80.5 | 80.0 | 83.7 |
| 125.4 | 101.8 | 88.5 | 82.6 | 82.0 | 86.3 |
| 129.7 | 105.7 | 91.5 | 85.0 | 84.2 | 89.0 |
| 133.3 | 109.4 | 94.6 | 87.5 | 86.6 | 91.8 |
| 136.7 | 112.8 | 97.6 | 90.1 | 89.2 | 94.7 |
| 139.7 | 116.1 | 100.6 | 92.8 | 91.8 | 97.5 |
| 142.4 | 119.2 | 103.6 | 95.6 | 94.6 | 100.4 |
| 144.8 | 122.0 | 106.5 | 98.4 | 97.3 | 103.2 |
| 146.9 | 124.8 | 109.4 | 101.2 | 100.1 | 106.0 |
| 148.9 | 127.3 | 112.2 | 104.0 | 102.9 | 108.8 |
| 150.6 | 129.7 | 114.9 | 106.8 | 105.7 | 111.5 |
| 152.2 | 132.0 | 117.5 | 109.5 | 108.4 | 114.1 |
| 153.9 | 134.2 | 120.0 | 112.2 | 111.1 | 116.7 |
| 155.5 | 136.3 | 122.5 | 114.8 | 113.7 | 119.2 |
| 157.0 | 138.3 | 124.8 | 117.3 | 116.2 | 121.6 |
| 158.5 | 140.3 | 127.2 | 119.8 | 118.7 | 124.0 |
| 159.9 | 142.2 | 129.4 | 122.3 | 121.2 | 126.3 |
| 161.2 | 144.1 | 131.6 | 124.6 | 123.6 | 128.5 |
| 162.3 | 145.8 | 133.7 | 126.9 | 125.9 | 130.7 |
| 163.4 | 147.5 | 135.8 | 129.1 | 128.1 | 132.8 |
| 164.4 | 149.1 | 137.7 | 131.3 | 130.3 | 134.9 |
| 165.4 | 150.6 | 139.6 | 133.4 | 132.5 | 136.8 |
| 166.3 | 152.0 | 141.4 | 135.4 | 134.5 | 138.7 |
| 167.1 | 153.4 | 143.2 | 137.4 | 136.5 | 140.6 |

| TN 31 | TN 32 | TN 33 | TN 34 | TN 35 | TN 36 |
|---|---|---|---|---|---|
| 75.0 | 75.0 | 74.9 | 74.8 | 75.0 | 75.0 |
| 76.3 | 80.6 | 99.2 | 107.3 | 82.5 | 76.8 |
| 78.9 | 88.0 | 115.6 | 127.4 | 91.9 | 80.0 |
| 82.2 | 95.3 | 127.0 | 140.3 | 100.9 | 84.2 |
| 85.9 | 101.9 | 134.6 | 148.0 | 108.7 | 88.7 |
| 89.7 | 107.7 | 140.0 | 153.2 | 115.1 | 93.2 |
| 93.5 | 112.7 | 144.6 | 157.5 | 120.6 | 97.5 |
| 97.1 | 117.2 | 148.6 | 161.2 | 125.3 | 101.5 |
| 100.7 | 121.3 | 152.0 | 164.3 | 129.5 | 105.2 |
| 104.1 | 124.9 | 154.7 | 166.5 | 133.1 | 108.7 |
| 107.3 | 128.2 | 157.4 | 168.9 | 136.3 | 111.9 |
| 110.5 | 131.2 | 159.7 | 170.8 | 139.2 | 114.9 |
| 113.5 | 134.0 | 161.6 | 172.3 | 141.8 | 117.7 |
| 116.3 | 136.5 | 163.1 | 173.3 | 144.0 | 120.2 |
| 119.0 | 138.8 | 164.4 | 174.1 | 145.9 | 122.5 |
| 121.6 | 140.9 | 165.5 | 174.8 | 147.6 | 124.6 |
| 124.1 | 142.9 | 166.6 | 175.4 | 149.1 | 126.6 |
| 126.4 | 144.7 | 167.6 | 175.9 | 150.4 | 128.4 |
| 128.7 | 146.5 | 168.8 | 176.7 | 151.7 | 130.0 |
| 130.9 | 148.3 | 170.0 | 177.7 | 153.0 | 131.6 |
| 133.1 | 150.0 | 171.2 | 178.6 | 154.3 | 133.1 |
| 135.2 | 151.6 | 172.2 | 179.2 | 155.4 | 134.6 |
| 137.2 | 153.2 | 173.1 | 179.6 | 156.5 | 135.9 |
| 139.1 | 154.7 | 173.8 | 179.9 | 157.4 | 137.2 |
| 141.0 | 156.0 | 174.5 | 180.1 | 158.2 | 138.3 |
| 142.8 | 157.3 | 175.0 | 180.2 | 158.9 | 139.4 |
| 144.5 | 158.5 | 175.5 | 180.3 | 159.6 | 140.4 |
| 146.2 | 159.7 | 176.0 | 180.3 | 160.1 | 141.4 |
| 147.8 | 160.7 | 176.4 | 180.3 | 160.6 | 142.3 |
| 149.3 | 161.8 | 176.9 | 180.4 | 161.1 | 143.1 |

| TN 37 | TN 38 | TN 39 | TN 40 | TN 41 | TN 42 |
|---|---|---|---|---|---|
| 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| 75.4 | 75.1 | 75.0 | 75.0 | 75.0 | 75.0 |
| 76.4 | 75.4 | 75.1 | 75.0 | 75.0 | 75.0 |
| 78.1 | 76.0 | 75.3 | 75.1 | 75.0 | 75.1 |
| 80.1 | 76.8 | 75.6 | 75.2 | 75.1 | 75.1 |
| 82.5 | 77.9 | 76.1 | 75.4 | 75.2 | 75.1 |
| 85.1 | 79.2 | 76.7 | 75.7 | 75.3 | 75.2 |
| 87.8 | 80.7 | 77.4 | 76.0 | 75.5 | 75.3 |
| 90.4 | 82.3 | 78.3 | 76.4 | 75.7 | 75.4 |
| 93.1 | 84.0 | 79.3 | 77.0 | 75.9 | 75.6 |
| 95.6 | 85.8 | 80.3 | 77.5 | 76.3 | 75.8 |
| 98.1 | 87.6 | 81.5 | 78.2 | 76.6 | 76.0 |
| 100.5 | 89.3 | 82.6 | 78.9 | 77.1 | 76.3 |
| 102.8 | 91.1 | 83.9 | 79.7 | 77.5 | 76.6 |
| 105.0 | 92.8 | 85.1 | 80.6 | 78.1 | 76.9 |
| 107.0 | 94.6 | 86.4 | 81.4 | 78.6 | 77.3 |
| 109.0 | 96.2 | 87.7 | 82.3 | 79.3 | 77.7 |
| 110.8 | 97.8 | 88.9 | 83.3 | 79.9 | 78.2 |
| 112.5 | 99.4 | 90.2 | 84.2 | 80.6 | 78.6 |

| | | | | | |
|---|---|---|---|---|---|
| 114.2 | 100.9 | 91.5 | 85.2 | 81.3 | 79.2 |
| 115.8 | 102.4 | 92.7 | 86.1 | 82.0 | 79.7 |
| 117.3 | 103.8 | 93.9 | 87.1 | 82.8 | 80.3 |
| 118.7 | 105.2 | 95.1 | 88.1 | 83.5 | 80.9 |
| 120.1 | 106.5 | 96.3 | 89.1 | 84.3 | 81.5 |
| 121.4 | 107.8 | 97.5 | 90.1 | 85.1 | 82.1 |
| 122.7 | 109.1 | 98.6 | 91.0 | 85.9 | 82.8 |
| 123.9 | 110.3 | 99.7 | 92.0 | 86.7 | 83.5 |
| 125.0 | 111.4 | 100.8 | 93.0 | 87.5 | 84.2 |
| 126.1 | 112.6 | 101.9 | 93.9 | 88.4 | 84.9 |
| 127.1 | 113.7 | 102.9 | 94.9 | 89.2 | 85.6 |

| TN 43 | TN 44 | TN 45 | TN 46 | Avg tray 1 | Avg tray 2 |
|---|---|---|---|---|---|
| 75.0 | 75.1 | 75.5 | 76.0 | 75.0 | 75.0 |
| 75.0 | 75.4 | 76.1 | 76.8 | 79.2 | 82.4 |
| 75.1 | 75.6 | 76.6 | 77.5 | 82.6 | 88.5 |
| 75.1 | 75.8 | 77.1 | 78.1 | 85.5 | 93.8 |
| 75.2 | 76.0 | 77.5 | 78.5 | 87.9 | 98.2 |
| 75.3 | 76.1 | 77.8 | 78.9 | 89.9 | 102.0 |
| 75.3 | 76.3 | 78.1 | 79.3 | 91.8 | 105.6 |
| 75.4 | 76.5 | 78.3 | 79.5 | 93.6 | 109.1 |
| 75.5 | 76.6 | 78.6 | 79.8 | 95.3 | 112.3 |
| 75.6 | 76.7 | 78.8 | 80.0 | 96.9 | 115.3 |
| 75.8 | 76.9 | 78.9 | 80.2 | 98.4 | 118.3 |
| 75.9 | 77.1 | 79.1 | 80.3 | 99.9 | 121.1 |
| 76.1 | 77.2 | 79.3 | 80.5 | 101.3 | 123.7 |
| 76.4 | 77.4 | 79.4 | 80.6 | 102.5 | 126.2 |
| 76.6 | 77.6 | 79.6 | 80.7 | 103.8 | 128.5 |
| 76.9 | 77.9 | 79.7 | 80.9 | 104.9 | 130.7 |
| 77.2 | 78.1 | 79.9 | 81.0 | 106.0 | 132.9 |
| 77.5 | 78.4 | 80.1 | 81.1 | 107.1 | 134.9 |
| 77.9 | 78.7 | 80.2 | 81.2 | 108.2 | 136.9 |
| 78.3 | 79.0 | 80.4 | 81.4 | 109.3 | 139.0 |
| 78.8 | 79.3 | 80.6 | 81.5 | 110.3 | 140.9 |
| 79.2 | 79.7 | 80.9 | 81.6 | 111.4 | 142.8 |
| 79.7 | 80.1 | 81.1 | 81.8 | 112.3 | 144.6 |
| 80.3 | 80.5 | 81.3 | 81.9 | 113.3 | 146.3 |
| 80.8 | 80.9 | 81.6 | 82.1 | 114.1 | 147.9 |
| 81.4 | 81.4 | 81.9 | 82.3 | 115.0 | 149.4 |
| 82.0 | 81.9 | 82.1 | 82.4 | 115.8 | 150.9 |
| 82.6 | 82.3 | 82.4 | 82.6 | 116.6 | 152.3 |
| 83.2 | 82.8 | 82.7 | 82.8 | 117.4 | 153.6 |
| 83.8 | 83.4 | 83.0 | 83.0 | 118.2 | 154.9 |

| Avg tray 3 | Avg tray 4 |
|---|---|
| 75.0 | 75.0 |
| 82.4 | 82.4 |
| 88.5 | 88.5 |
| 93.8 | 93.8 |
| 98.2 | 98.2 |
| 102.0 | 102.0 |
| 105.6 | 105.6 |
| 109.1 | 109.1 |

| | |
|---|---|
| 112.3 | 112.3 |
| 115.3 | 115.3 |
| 118.3 | 118.3 |
| 121.1 | 121.1 |
| 123.7 | 123.7 |
| 126.2 | 126.2 |
| 128.5 | 128.5 |
| 130.7 | 130.7 |
| 132.9 | 132.9 |
| 134.9 | 134.9 |
| 136.9 | 136.9 |
| 139.0 | 139.0 |
| 140.9 | 140.9 |
| 142.8 | 142.8 |
| 144.6 | 144.6 |
| 146.3 | 146.3 |
| 147.9 | 147.9 |
| 149.4 | 149.4 |
| 150.9 | 150.9 |
| 152.3 | 152.3 |
| 153.6 | 153.6 |
| 154.9 | 154.9 |

# APPENDIX C

File 18 in ANSYS for the SHGR Model

```
/COM,ANSYS-PC REVISION  4.4        A  1      13.4962        9/ 9/1993
/PREP7
KAN,-1
ET,1,55
ETLIST
MP,KXX,1,.0996
MP,DENS,1,47.1
MP,C,1,.366
MP,C,2,1.
MP,KXX,2,.375
MP,DENS,2,62.4
MP,DENS,5,.025
MP,KXX,5,.025
MP,DENS,5,2.
MP,C,5,.24
MP,C,6,.32
MP,KXX,6,.202
MP,DENS,6,21.5
MP,DENS,7,56.18
MP,KXX,7,.08
MP,C,7,.46
MP,C,8,.24
MP,DENS,8,.0727
MP,KXX,8,.0145
MP,C,8,.24
MP,C,9,.7
MP,KXX,9,.392
MP,DENS,9,81.15
MP,DENS,10,488.
MP,KXX,10,5.32
MP,C,10,.11
MPLIST
SAVE
K
K,,.5625
K,,.5625,.0031
K,,.0031,.0031
K,,.0031,.125
K,,.5625,.125
K,,.5625,.1281
K,,.0031,.1281
K,,.0031,.25
K,,.5625,.25
K,,.5625,.2531
K,,.0031,.2531
K,,.0031,.375
K,,.5625,.375
K,,.5625,.3781
K,,.0031,.3781
K,,.0031,.5
K,,,.5
SAVE
KPLOT
```

```
L,,,20
L,       1,      2,20
KPLOT
L,       1,      2,30
L,       3,      4,30
L,       5,      6,30
L,       7,      8,30
L,       9,     10,30
L,      11,     12,30
L,      13,     14,30
L,      15,     16,30
L,      18,      1,30
L,       4,      5,7
L,       8,      9,7
L,      12,     13,7
L,      16,     17,7
L,      17,     18,1
LPLOT
SAVE
LOCAL,11,0,,.5625
CSYS,11
LSYMM,2,ALL
LPLOT
RESUME
LOCAL,11,0,.5625
CSYS,11
LPLOT
LSYMM,1,ALL
LPLOT
KPLOT
KLIST
AL,ALL
LPLOT
L,      16,     13,1
L,      12,      9,1
L,       8,      5,1
L,       4,      1,1
L,      22,     19,1
L,      23,     26,1
L,      27,     30,1
L,      31,     34,1
LPLOT
AL,P44A,        6
         1      15      33      16       2      32
AL,P44A,        6
        31       3      17      34      18       4
NUMMRG,ALL
AL,P44A,        6
        32       1      15      33      16       2
KPLOT
KLIST
NUMCMP,KPOI
KLIST
```

```
LPLOT
LDEL,     31,     31,1,      0
LDEL,     30,     30,1,      0
LDEL,     29,     29,1,      0
LDEL,     36,     36,1,      0
LDEL,     35,     35,1,      0
LDEL,     34,     34,1,      0
LPLOT
AL,ALL
L,      5,      8,1
L,      9,     12,1
L,     13,     16,1
L,     26,     25,1
L,     24,     23,1
L,     22,     21,1
LLIST
AL,P44A,     12
     29      3      17      36      18       4       5      19      35      20
      6     30
AL,P44A,      6
      3     17      36      18       4      29
AL,P44A,      6
      5     19      35      20       6      30
AL,P44A,      6
      7     21      34      22       8      31
AL,P44A,     10
     14      9      32      10      29      11      30      12      31      13

AL,P44A,     10
     28     23      33      24      36      25      35      26      34      27

APLOT
AATT,7,,1
ALIST
SAVE
AMESH,ALL
ARSEL,,5,6
APLOT
LSAR
LPLOT
LSSE,LINE,          9
LPLOT
LLIST
ACLEAR,5,6
LPLOT
LLIST
L,9,,20
L,9,9,20
LDVS,9,,20
LSALL
LPLOT
LDVS,23,,20
ARALL
```

```
APLOT
AMESH,ALL
SAVE
LPLOT
CSYS,0
KPLOT
K,,.1667,.017
RESUME
LPLOT
APLOT
ADELE,ALL
RESUME
LPLOT
ACLEAR,ALL
ADELE,1,4
LPLOT
LDEL,      2,      2,1,      0
LDEL,     15,     15,1,      0
LDEL,     18,     18,1,      0
LDEL,      4,      4,1,      0
LDEL,      6,      6,1,      0
LDEL,     20,     20,1,      0
LDEL,     22,     22,1,      0
LDEL,      8,      8,1,      0
LPLOT
KPLOT
K,,.1667,.017
K,,.1667,.0031
KDEL,     30
KDEL,     29
CSYS,0
K,,.1667,.0031
K,,.1667,.017
SAVE
/COM,ANSYS-PC REVISION  4.4       A  1     16.0971     9/ 9/1993
/PREP7
RESUME
LPLOT
LDEL,      1,      1,1,      0
LDEL,      4,      4,1,      0
LDEL,      6,      6,1,      0
LDEL,      8,      8,1,      0
KPLOT
K,,.1667,.0031
K,,.1667,.017
K,,.5625,.017
SAVE
KGEN,4,19,21,,,.125
KLIST
KLIST
L,     19,      3,21
L,     21,     20,21
L,     22,     23,21
```

```
LPLOT
LDEL,      2,      2,1,     0
LDEL,      3,      3,1,     0
LDEL,      5,      5,1,     0
LDEL,      7,      7,1,     0
LDEL,      6,      6,1,     0
LPLOT
KPLOT
L,     22,      7,21
L,     24,     23,21
L,     25,     11,21
L,     27,     26,21
L,     28,     15,21
L,     30,     29,21
LPLOT
KPLOT
LPLOT
LDEL,      1,      1,1,     0
LDEL,      4,      4,1,     0
LDEL,      2,      2,1,     0
LDEL,      3,      3,1,     0
LDEL,      5,      5,1,     0
LDEL,      6,      6,1,     0
LDEL,      7,      7,1,     0
LDEL,      8,      8,1,     0
KPLOT
L,     19,      3,21
L,     21,     20,21
L,     22,      7,21
L,     24,     23,21
L,     26,     27,21
L,     11,     25,21
L,     29,     30,21
L,     15,     28,21
L,      1,      2,30
L,      6,      5,30
L,      9,     10,30
L,     13,     14,30
L,      4,     19,9
L,     22,      8,9
L,     12,     25,9
L,     16,     28,9
L,     20,     19,3
L,     23,     22,3
L,     26,     25,3
L,     29,     28,3
L,     30,     15,3
L,     27,     11,3
L,     24,      7,3
L,     21,      3,3
LPLOT
L,      3,      2,1
L,      7,      6,1
```

```
L,     11,     10,1
L,     15,     14,1
L,     16,     13,1
L,     12,      9,1
L,      8,      5,1
L,      4,      1,1
KPLOT
K,,.5625,.5
SAVE
off
on
KPLOT
K,,.5625,.5417
K,,.5625,.5521
K,,.5625,-.0417
K,,.5625,-.0521
K,,.5625,-.0625
KPLOT
K,,.1563,-.0625
KDELE,37
K,,-.1563,-.0625
K,,-.1563,-.0521
K,,-.0313,-.0521
K,,-.0208,-.0521
KLIST
KDELE,40
K,,-.0208,-.0417
K,,-.0208,.5417
K,,-.0313,.5521
KPLOT
L,     40,     34,30
L,     35,     39,30
L,     39,     42,30
L,     41,     40,30
L,     41,     32,30
L,     33,     42,30
L,     37,     36,40
L,     38,     39,10
L,     34,     35,1
L,     35,     36,1
L,     38,     37,1
L,     33,     32,1
LPLOT
LDEL,     42,     42,1,      0
LPLOT
KPLOT
K,,-.0208
K,,-.0208,.5
L,     43,     44,20
L,     43,      1,2
LPLOT
L,     44,     18,2
L,     43,     40,4
```

```
L,     44,     41,4
L,     31,     32,4
L,     34,      2,4
L,     17,     31,30
L,     30,     31,7
L,     14,     27,7
L,     10,     24,7
L,      6,     21,7
LPLOT
LDEL,     57,     57,1,      0
LDEL,     52,     52,1,      0
LDEL,     14,     14,1,      0
LPLOT
L,     17,     18,1
L,     44,     18,2
L,     17,     31,30
LPLOT
SAVE
NUMMRG,ALL
NUMCMP,ALL
SAVE
AL,P44A,      6
     19      23       2      61      16      10
AL,P44A,      6
     20      24       4      60      17      11
AL,P44A,      6
     22      26       7      58      57      13
AATT,1,,1
ALIST
AL,P44A,      6
     21      25       5      59      18      12
ARSE,AREA,          4
AATT,2,,1
ALIST
AMESH,ALL
NPLOT
ACLEAR
EPLOT
ACLEAR,ALL
LPLOT
ARALL
ADELE,ALL
LPLOT
LDVS,      2,  0.0000000E+00,     27,    1.000000
LDVS,      2,  0.0000000E+00,     27,    1.000000
LDVS,      2,  0.0000000E+00,     27,    1.000000
LDVS,      1,  0.0000000E+00,     27,    1.000000
LDVS,      4,  0.0000000E+00,     27,    1.000000
LDVS,      3,  0.0000000E+00,     27,    1.000000
LDVS,      5,  0.0000000E+00,     27,    1.000000
LDVS,      6,  0.0000000E+00,     27,    1.000000
LDVS,      7,  0.0000000E+00,     27,    1.000000
LDVS,      8,  0.0000000E+00,     27,    1.000000
```

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AL,P44A,      6
       5     25      21      12      18      59
AATT,2,,1
AMESH,ALL
EPLOT
SAVE
FINISH
/EOF
/COM,ANSYS-PC REVISION  4.4        A  1       8.1790      9/10/1993
/PREP7
RESUME
LPLOT
EPLOT
ACLEAR,ALL
LPLOT
LDVS,     16,  0.0000000E+00,    40,    1.000000
LDVS,     17,  0.0000000E+00,    40,    1.000000
LDVS,     18,  0.0000000E+00,    40,    1.000000
AMESH ,      1
ALIST
ARALL
ALIST
AL,P44A,      6
       2     23      19      10      16      61
AL,P44A,      6
       4     24      20      11      17      60
AL,P44A,      6
       7     26      22      13      57      58
ALIST
ARSEL,,2,4
APLOT
AATT,1,,1
ALIST
AMESH,ALL
LPLOT
AL,P44A,      4
       6     25       5      28
AMESH,ALL
EPLOT
ACLEAR,5
LPLOT
AL,P44A,      8
       2     30       1      23       3      24       4      29
AL,P44A,      4
       8     26       7      27
AL,P44A,      4
       2     30       1      23
AL,P44A,      4
       3     24       4      29
ARSEL,,5,7
APLOT
ARSEL,,4,7
APLOT
```

```
ARSEL,,5,8
APLOT
AATT,9,,1
ALIST
AMESH,ALL
SAVE
LPLOT
AL,P44A,      5
      6      21       9      17      33
AL,P44A,      5
     33       6      21      36      17
AMESH,ALL
ACLEAR,9
AL,P44A,      5
      8      22      35      18      34
AL,P44A,      5
      1      19      38      15      31
AL,P44A,      5
      3      20      37      16      32
ARSEL,,9,12
APLOT
AATT,7,,1
AMESH,ALL
EPLOT
LPLOT
AL,P44A,     10
     14      13      35      12      36      11      37      10      38       9

ALIST
ARSEL,,13
APLOT
AATT,7,,1
AMESH,ALL
ACLEAR,13
APLOT
LSAR
LPLOT
LDVS,      9,  0.0000000E+00,     40,    1.000000
LDVS,     13,  0.0000000E+00,     10,    1.000000
LDVS,     12,  0.0000000E+00,     10,    1.000000
LDVS,     11,  0.0000000E+00,     10,    1.000000
LDVS,     10,  0.0000000E+00,     10,    1.000000
AMESH,ALL
LSALL
LPLOT
AL,P44A,      4
      9      52      42      51
ARSEL,,14
APLOT
AATT,8,,1
AMESH,ALL
SAVE
LPLOT
```

```
AL,P44A,      4
      57      55      43      54
AL,P44A,      5
      57      55      43      54      52
AL,P44A,      6
      57      55      43      54      52      14
AL,P44A,      6
      39      56      15      38      51      53
AL,P44A,      6
      39      56      15      38      51      53
LPLOT
AL,P44A,      5
      39      56      15      51      53
ARSEL,,15,16
APLOT
AATT,5,,1
AMESH,ALL
EPLOT
SAVE
off
on
EPLOT
ACLEAR,     15
ACLEAR,     15
ACLEAR,     15
ACLEAR,     15
ACLEAR,4
ARALL
LSALL
ACLEAR,4
LPLOT
LDVS,     57,   0.0000000E+00,     40,    1.000000
AMESH,ALL
ALIST
AL,P44A,      5
      40      46      49      45      48
ARSEL,,17
ARSEL,,17
APLOT
AATT,10,,1
AMESH,ALL
LPLOT
AL,P44A,     10
      50      44      41      40      47      39      53      42      54      43

ARSEL,,18
APLOT
AATT,6,,1
AMESH,ALL
ARALL
LSALL
EPLOT
NPLOT
```

```
NASE,NODE,        580
NASE,NODE,        847
NLIST
NALL
SAVE
off
on
LPLOT
LCVS,     46, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
LCVS,     41, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
LCVS,     44, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
NT,ALL,TEMP,76.
/PBC,ALL,1
NPLOT
SBCTRA
TIME,0
ITER,-1
LWRITE
NTDELE,ALL,TEMP
NPLOT
*USE,load2,1/60,-3,197.8,202.5
RESUME
FINISH
/PREP7
RESUME
NUMMRG,ALL
WFRONT
WAVES
LPLOT
LCVS,     46, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
LCVS,     41, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
LCVS,     44, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
SBCTRA
NT,ALL,TEMP,76.
NPLOT
/PBC,ALL,1
NPLOT
TIME,0
ITER,-1
LWRITE
NTDELE,ALL,TEMP
NPLOT
*USE,load2,1/60,-3,197.8,202.5
*USE,load2,10/60,-20,198.8,200.
*USE,load2,20/60,-23,197.9,188.
*USE,load2,.5,-23,194.6,180.
AFWRITE
FINISH
/PREP7
RESUME
MPLIST
ALIST
ACLEAR,5,19
```

```
EPLOT
NTDELE,ALL,TEMP
APLOT
ARSE,AREA,          7
ARAS,AREA,          8
ARAS,AREA,          5
ARAS,AREA,          6
AATT,7,,1
AMESH,ALL
ARALL
ARSE,AREA,         15
ARAS,AREA,         16
APLOT
AATT,3,,1
AMESH,ALL
ARALL
APLOT
ARSE,AREA,         14
APLOT
AATT,6,,1
AMESH,ALL
ARALL
APLOT
ARSE,AREA,         11
ARAS,AREA,         12
ARAS,AREA,          9
ARAS,AREA,         10
ARAS,AREA,         13
APLOT
AATT,5,,1
AMESH,ALL
ARALL
APLOT
ARSE,AREA,         17
APLOT
AATT,8,,1
AMESH,ALL
ARALL
ARSEL,,18
APLOT
AATT,4,,1
AMESH,ALL
ARALL
APLOT
ALIST
WFRONT
SAVE
WAVES
EPLOT
NPLOT
LPLOT
LCVS,     46, 0.8800000      ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
LCVS,     41, 0.8800000      ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
```

```
LCVS,     44, 0.8800000     ,  76.00000     , 0,   0, 0.0000000E+00, 0.0000
SBCTRA
NT,ALL,TEMP,76
/PBC,ALL,1
TIME,0
ITER,-1
LWRITE
NTDELE,ALL,TEMP
NPLOT
*USE,load2,1/60,-3,197.8,202.5
*USE,load2,10/60,-20,198.8,200.
*USE,load2,20/60,-23,197.9,188.
*USE,load2,.5,-23,194.6,180.
AFWRITE
AFLIST
FINISH
/INPUT,27
FINISH
/POST1
STRESS,THER
SET,,,,,10/60
PLNSTR,TEMP
/title,Self-Heating Group Ration (SHGR) with corn and water at 10 minut
/EDGE,1,1
/RESET
/PLOFF,,1
/CONTOUR,1,,85,15
/replot
PLNSTR,TEMP
/EDGE,1,1
PLNSTR,TEMP
off
/replot
halo,ahdpjxl,.85,1,3
/replot
halo,print,ahdpjxl,.85,1,3
/replot
halo,print
/edge,1,0
/replot
halo,print,ahdpjxl,.85,1,3
/replot
halo,print
on
NPLOT
LPATH,1029,1071
PDEF,INTR,TEMP,TEMP
PCALC,INTG,AREA,TEMP,S
PCALC,DIV,AVG,AREA,S
PVIEW,PLOT,TEMP,AREA,AVG
/GRAPH,GRID,1
/TITLE,Average temperature of the bottom tray of corn at 10 minutes.
/replot
```

```
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,847,887
PDEF,INTR,TEMP,TEMP
PCALC,intg,AREA,TEMP,S
PCALC,DIV,AVG,AREA,S
PVIEW,PLOT,TEMP,AREA,AVG
/TITLE,Average temperature of the third tray of water at 10 minutes.
/replot
off
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,2729,2526
PDEF,INTR,TEMP,TEMP
PCALC,intg,area,temp,S
PCALC,div,avg,area,S
PVIEW,PLOT,TEMP,AREA,AVG
/title,Average temperature of the top tray of corn at 10 minutes.
/replot
off
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
*CREATE,temtu
PDEF,INTR,TEMP,TEMP,
PCALC,intg,AREA,TEMP,S
PCALC,div,avg,area,S,
PVIEW,PLOT,TEMP,AREA,AVG,
*END,
*USE,TEMTU
EPLOT
ELIST
EALL
LPATH,3577,3576
PDEF,INTR,FLUX,TFY
PCALC,INTG,FLOW,FLUX,S
PVIEW,PLOT,FLUX,FLOW
*GET,PMIN,LOSS,FLOW
*GET,LOSS,PMIN,FLOW
/TLA, 0.132, 0.430,Flow Loss = -17.1 Btu/hr*ft
/TLABEL,delete,,Flow Loss = -17.1 Btu/hr*ft
/TLA, 0.107, 0.430,Flow Loss = 17.9 Btu/hr*ft
/replot
/title, Heat flow (q) and heat flux (q") for the bottom side at 10 minu
/replot
off
```

```
/replot
/replot
on
/TLABEL,delete,,Flow Loss = 17.9 Btu/hr*ft
/replot
/TLA,-0.229,-0.242,Flow Loss = 17.9 Btu/hr*ft
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,3660,3659
PDEF,INTR,FLUX,TFY
PCALC,INTG,FLOW,FLUX,S
PVIEW,PLOT,FLUX,FLOW
*GET,LOSS,pmax,FLOW
/TLABEL,delete,,Flow Loss = 17.9 Btu/hr*ft
/TLA,-0.241,-0.219,Flow Loss = 0.34 Btu/hr*ft
/title,Heat flow (q) and heat flux (q") for the top side at 10 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
PLPATH,path,,TEMP
/TLABEL,delete,,Flow Loss = 0.34 Btu/hr*ft
/title,Temperature along the top side of the SHGR at 10 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,3577,3576
PLPATH,path,,TEMP
/title,Temperature along the bottom side of the SHGR at 10 minutes.
off
! /RPLOT
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,3577,3660
PDEF,INTR,FLUX,TFY
PDEF,INTR,FLUX,tfx
PCALC,INTG,FLOW,FLUX,S
PVIEW,PLOT,FLUX,FLOW
PRANGE,,.01
PLPATH,path,,TEMP
PVIEW,PLOT,FLUX,FLOW
```

```
PRANGE,,.03
PVIEW,PLOT,FLUX,FLOW
PRANGE,,0
/title,Heat flow (q) and heat flux (q") for the left side at 10 minutes
off
/replot
on
*GET,LOSS,pmax,FLOW
*GET,LOSS,pmin,FLOW
/TLA,-0.409,-0.173,Flow loss = 0.44 Btu/hr*ft
/replot
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
/TLABEL,delete,,Flow loss = 0.44 Btu/hr*ft
PLPATH,path,,TEMP
/title,Temperature along the left side of the SHGR at 10 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
PLVECT,tf
/title,Thermal flux vectors for the SHGR with water at 10 minutes.
off
/replot
halo,print,ahdpjxl,.85,1,3
/replot
/replot
halo,print
on
RESET
STRESS,THER
SET,,,,,20/60
PLNSTR,TEMP
/title,Self-Heating Group Ration (SHGR) with corn and water at 10 minut
off
/replot
halo,print,ahdpjxl,.85,1,3
/replot

halo,print
/title,Self-Heating Group Ration (SHGR) with corn and water at 20 minut
halo,print,ahdpjxl,.85,1,3
/replot
halo,print
on
PLVECT,tf
/title,Thermal flux vectors for the SHGR with corn and water at 20 minu
```

```
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
halo,print,ahdpjxl,.85,1,3
/replot
halo,print
on
LPATH,1029,1071
*USE,temtu
/title Average temperature of the bottom tray of corn at 20 minutes.
/replot
off
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,847,887
*use,temtu
/title,Average temperature of the third tray of water at 20 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
lpath,2729,2526
*use,temtu
/title,Average temperature of the top tray of corn at 20 minutes.
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,3577,3576
PDEF,INTR,FLUX,TFY
PCALC,INTG,FLOW,FLUX,S
PVIEW,PLOT,FLUX,FLOW
*GET,LOSS,PMIN,FLOW
/TLA,-0.178,-0.202,Flow Loss = 15.9 Btu/hr*ft
/title,Heat flow (q) and heat flux (q") for the bottom side at 20 minut
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
*CREATE,bot
PDEF,INTR,FLUX,TFY,
PCALC,INTG,FLOW,FLUX,S,
PVIEW,PLOT,FLUX,FLOW,
*GET,LOSS,PMIN,FLOW,
*END,
*USE,bot
```

```
LPATH,3660,3659
PDEF,INTR,FLUX,TFY
PCALC,INTG,FLOW,FLUX,S
PVIEW,PLOT,FLUX,FLOW
*GET,LOSS,pmax,FLOW
/TLABEL,delete,,Flow Loss = 15.9 Btu/hr*ft
/TLA,-0.195,-0.167,Flow Loss = 2.2 Btu/hr*ft
off
/replot
/title,Heat flow (q) and heat flux (q") for the top side at 20 minutes.
/replot
on
/TLABEL,delete,,Flow Loss = 2.2 Btu/hr*ft
/TLA,-0.392, 0.085,Flow Loss = 2.2 Btu/hr*ft
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
*USE,top
*USE,topp
*CREATE,top
PDEF,INTR,FLUX,TFY,
PCALC,INTG,FLOW,FLUX,S,
PVIEW,PLOT,FLUX,FLOW,
*GET,LOSS,pmax,FLOW,
*END,
*USE,top
/TLABEL,delete,,Flow Loss = 2.2 Btu/hr*ft
PLPATH,path,,TEMP
/title,Temperature along the top side of the SHGR at 20 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
! HLAO,PRINT
halo,print
lpath,3577,3576
*use,bot
/replot
on
PLPATH,path,,TEMP
/title,Temperature along the bottom side of the SHGR at 20 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
LPATH,3577,3660
PDEF,INTR,FLUX,TFX
PCALC,INTG,FLOW,FLUX,S
```

```
PVIEW,PLOT,FLUX,FLOW
*GET,LOSS,pmin,FLOW
/TLA,-0.224,-0.259,Flow Loss = 1.2 Btu/hr*ft
/title,Heat flow (q) and heat flux (q") fro the left side at 20 minutes
off
/replot
/title,Heat flow (q) and heat flux (q") for the left side at 20 minutes
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
plpath
on
/TLABEL,delete,,Flow Loss = 1.2 Btu/hr*ft
PLPATH,path,,TEMP
/title,Temperature along the left side of the SHGR at 20 minutes.
off
/replot
halo,print,ahdpjxl,.75,1,3
/replot
halo,print
on
*CREATE,left
PDEF,INTR,FLUX,TFX,
PCALC,INTG,FLOW,FLUX,S,
PVIEW,PLOT,FLUX,FLOW,
*GET,LOSS,pmin,FLOW,
*END,
*USE,left
NPLOT
NSEL,PICK
/COM,ANSYS-PC REVISION  4.4       A  1     16.3482      9/13/1993
/POST1
STRESS,THER
SET,,,,,.5
/CONTOUR,1,,85,15
/Title,Self-Heating Group Ration (SHGR) with corn and water at 30 minut
PLNSTR,TEMP
off
halo,print,ahdpjxl,.85,1,3
/replot
halo,print
on
/PLOFF,,1
/GRAPH,grid,1
FINISH
/EOF
/COM,ANSYS-PC REVISION  4.4       A  1     16.5493      9/13/1993
/PREP7
RESUME
APLOT
/PNUM,AREA,1
APLOT
```

```
APLOT
NPLOT
NTDELE,ALL,TEMP
NT,ALL,TEMP,76.
TIME,0
ITER,-1
LWRITE
NTDELE,ALL,TEMP
NPLOT
*USE,load2,1/60,-3,197.8,202.5
*USE,load2,10/60,-20,198.8,200.
*USE,load2,20/60,-23,197.9,188.
*USE,load2,.5,-23,194.6,180.
AFWRITE
AFLIST
EPLOT
ESEL,,3141
EPLOT
ELIST
EALL
ELIST
FINISH
/EOF
```

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## APPENDIX D

Macros used in ANSYS

## MACRO 'LOAD' FOR ANSYS MODEL

```
LOPTION,
TIME,ARG1,,
LOPTION,
ITER,ARG2,
ARSEL,,5,,,
ARASEL,,8,,
ARASEL,,7,,
NAREA,1,
NT,ALL,TEMP,ARG3,,
NALL,
ARALL,
ARSEL,,6,,
NAREA,1,
NT,ALL,TEMP,ARG4,,
NALL,
ARALL,
LOPTION,
LWRITE,
```

MACRO 'BOT' FOR ANSYS MODEL

```
PDEF,INTR,FLUX,TFY,

PCALC,INTG,FLOW,FLUX,S,

PVIEW,PLOT,FLUX,FLOW,

*GET,LOSS,PMIN,FLOW,
```

MACRO 'TOP' FOR ANSYS MODEL

```
PDEF,INTR,FLUX,TFY,

PCALC,INTG,FLOW,FLUX,S,

PVIEW,PLOT,FLUX,FLOW,

*GET,LOSS,PMAX,FLOW,
```

MACRO 'LEFT' FOR ANSYS MODEL

```
PDEF,INTR,FLUX,TFX,

PCALC,INTG,FLOW,FLUX,S,

PVIEW,PLOT,FLUX,FLOW,

*GET,LOSS,pmin,FLOW,
```